



US Army Corps
of Engineers

Construction Engineering
Research Laboratories



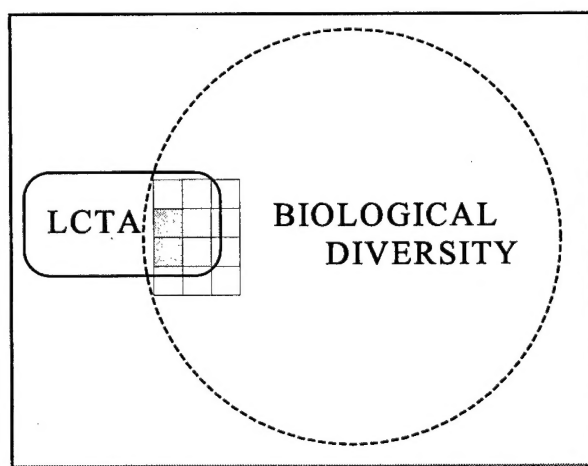
USACERL Technical Report 97/67
April 1997

Applicability of Land Condition Trend Analysis Data for Biological Diversity Assessment in the Southeastern United States

by
William R. Whitworth and Dr. Alison Hill

THIS QUALITY IMPROVED 4

19970721 016



Military lands not only support traditional training and testing activities, some of which are inherently damaging, but an increasingly diverse nonmilitary agenda. Army Regulation 200-3 requires commanders and land managers to consider the impacts of Army activities on biological diversity (biodiversity), which has been described simplistically as "the variety of life," yet is known to be composed of highly interactive biotic and abiotic elements that occur at multiple spatial and temporal scales. This report briefly reviews the concept of biodiversity, its primary attributes of composition, structure, and function, and the degree to which standard Land Condition Trend Analyses (LCTA) data can be applied to characterizing them.

Data collected under current methodology are most applicable towards characterizing the composition attribute of biodiversity, with structural and functional attributes receiving progressively lesser degrees of support. Although LCTA can provide biodiversity-relevant information at multiple scales, additional data sources should be used to address known deficiencies and gaps in coverage. Examples of analyses pertinent to biodiversity characterization are provided and will provide installation land managers greater flexibility in addressing biodiversity issues identified by Army regulation, government agencies, and the general public.

This document is a Legacy Program work product and does not suggest or reflect the policy, programs, or doctrine of the Department of the Army, Department of Defense, or United States Government.

Approved for public release; distribution is unlimited.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

A. HILL

AD NUMBER	DATE 3 JUN 97	DTIC ACCESSION NOTICE
1. REPORT IDENTIFYING INFORMATION		REQUESTER: 1. Put your mailing address on reverse of form. 2. Complete items 1 and 2. 3. Attach form to reports mailed to DTIC. 4. Use unclassified information only. 5. Do not order document for 6 to 8 weeks.
A. ORIGINATING AGENCY US ARMY CONSTRUCTION ENGINEER RESEARCH LABS		
B. REPORT TITLE AND/OR NUMBER APPLICABILITY OF LAND CONDITION TREND ANALYSIS DATA FOR BIOLOGICAL DIVERSITY.....		
C. MONITOR REPORT NUMBER TECHNICAL REPORT 97/67		
D. PREPARED UNDER CONTRACT NUMBER		
2. DISTRIBUTION STATEMENT APPROVED FOR PUBLIC RELEASE DISTRIBUTION IS UNLIMITED		DTIC: 1. Assign AD Number. 2. Return to requester.

DTIC Form 50
Mar 91

PREVIOUS EDITIONS ARE OBSOLETE

DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED

DO NOT RETURN IT TO THE ORIGINATOR

USER EVALUATION OF REPORT

REFERENCE: USACERL Technical Report 97/67, *Applicability of Land Condition Trend Analysis Data for Biological Diversity Assessment in the Southeastern United States*

Please take a few minutes to answer the questions below, tear out this sheet, and return it to USACERL. As user of this report, your customer comments will provide USACERL with information essential for improving future reports.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

2. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.)

3. Has the information in this report led to any quantitative savings as far as manhours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

4. What is your evaluation of this report in the following areas?

a. Presentation: _____

b. Completeness: _____

c. Easy to Understand: _____

d. Easy to Implement: _____

e. Adequate Reference Material: _____

f. Relates to Area of Interest: _____

g. Did the report meet your expectations? _____

h. Does the report raise unanswered questions? _____

i. General Comments. (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.)

5. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: _____

Telephone Number: _____

Organization Address: _____

6. Please mail the completed form to:

Department of the Army
CONSTRUCTION ENGINEERING RESEARCH LABORATORIES
ATTN: CECER-TR-I
P.O. Box 9005
Champaign, IL 61826-9005

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE April 1997	3. REPORT TYPE AND DATES COVERED Final		
4. TITLE AND SUBTITLE Applicability of Land Condition Trend Analysis Data for Biological Diversity Assessment in the Southeastern United States		5. FUNDING NUMBERS Reimbursable Order No. RP2897NI92		
6. AUTHOR(S) William R. Whitworth and Dr. Alison Hill				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Construction Engineering Research Laboratories (USACERL) P.O. Box 9005 Champaign, IL 61826-9005		8. PERFORMING ORGANIZATION REPORT NUMBER TR 97/67		
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Army Environmental Center ATTN: SFIM-AEC-ECN Aberdeen Proving Ground, MD 21010-5401		10. SPONSORING / MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words) Military lands not only support traditional training and testing activities, some of which are inherently damaging, but an increasingly diverse nonmilitary agenda. Army Regulation AR 200-3 requires commanders and land managers to consider the impacts of Army activities on biological diversity (biodiversity). Biodiversity has been described simplistically as "the variety of life", yet is known to be composed of highly interactive biotic and abiotic elements that occur at multiple spatial and temporal scales. This report briefly reviews the concept of biodiversity, its primary attributes of composition, structure and function, and the degree to which standard Land Condition Trend Analyses (LCTA) data can be applied towards characterizing them. Data collected under current methodology is most applicable towards characterizing the composition attribute of biodiversity, with structural and functional attributes receiving progressively lesser degrees of support. Although LCTA can provide biodiversity-relevant information at multiple scales, additional data sources should be utilized to address known deficiencies and gaps in coverage. Examples of analyses pertinent to biodiversity characterization are provided, and will provide installation land managers greater flexibility in addressing biodiversity issues identified by Army regulation, government agencies and the general public.				
14. SUBJECT TERMS biodiversity Land Condition Trend Analysis (LCTA) land management			15. NUMBER OF PAGES 84	16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT SAR	

Foreword

This study was conducted for the Legacy Resources Management Program under Project RP2897NI92, "Legacy-Biodiversity of Mil Lan"; Work Unit I92, "Regional Evaluation of DOD Natural Resources and Biodiversity." The technical monitor was Pam Klinger, SFIM-AEC-ECN.

The work was performed by the Natural Resource Assessment and Management Division (LL-N) of the Land Management Laboratory (LL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Dr. Alison Hill. Eric Schreiber, CSU Contractor, provided assistance with data analyses and table preparation. Dr. David J. Tazik is Acting Chief, CECER-LL-N, and Dr. William D. Severinghaus is Operations Chief, CECER-LL. The USACERL technical editor was Linda L. Wheatley, Technical Information Team.

COL James T. Scott is Commander and Dr. Michael J. O'Connor is Director of USACERL.

Contents

SF 298	1
Foreword	2
List of Figures and Tables	4
1 Introduction	7
Background	7
Objectives	9
Approach	9
Scope	10
Mode of Technology Transfer	10
2 Biological Diversity	11
Defining Biodiversity	11
The Regulatory Framework	19
3 The LCTA Program	21
Floristic Inventory	21
LCTA Plot Types	21
Plot Inventory	21
Long- and Short-Term Plot Monitoring	22
4 LCTA Data and Biodiversity Characterization	24
General Overview: The LCTA-Biodiversity Interface	24
Statistical Measures of Diversity	26
Descriptive Measures: The Characterization of Composition	33
Descriptive Measures: The Characterization of Structure	45
Descriptive Measures: The Characterization of Function	50
Interpretation of Biodiversity Summaries	54
5 Summary	60
Glossary	65
References	68
Distribution	

List of Figures and Tables

Figures

1	Spatial relationship of the LCTA bird survey area, small mammal transects, and optional herp pitfall array	23
2	Conceptual diagram illustrating the degree of overlap between standard LCTA data and biodiversity characterization	26
3	Graphical representation of community overlap between four hypothetical ecological communities along a known environmental gradient.	33
4	Number of unique and shared species between the LCTA Floristic Inventory and 1992 Plot Surveys for Fort Benning, GA	36
5	Number of unique and shared species between the LCTA Floristic Inventory and 1992 Plot Surveys for Fort Stewart, GA	36
6	Fort Benning plant diversity—ratio of native to introduced plant species based on 1992 LCTA plot data	37
7	Fort Benning plant diversity—ratio of annuals versus perennials based on 1992 LCTA plot data	39
8	Fort Benning plant diversity— growth form summary based on the LCTA floristic inventory and 1992 plot data	40
9	Percentages of canopy cover, when present, attributed to perennial and annual species	47
10	Percentage of perennial canopy cover attributed to coniferous and broadleaf species within deciduous (n=83 plots), coniferous (n=72), and mixed (n=18) plant communities	48
11	1992 percent ground cover summary for Fort Benning	48
12	1992 military ground disturbance summary	50

13	Total number of LCTA core plots (n=226) on Fort Benning exhibiting evidence of wind and water erosion	51
----	---	----

Tables

1	Matrix identifying indicator variables used in characterizing biodiversity at four hierarchical levels	25
2	Alpha diversity indices for LCTA small mammal and bird communities for two habitats on each of two Army installations in Texas	28
3	Beta diversity indices for LCTA small mammal and bird communities for two Army installations in Texas	32
4	Floral taxonomic diversity (richness) values based on LCTA Floristic Inventory and LCTA plot data for three Army installations in the southeastern United States	34
5	Bird community diversity at Camp Shelby, MS: Total number and frequency of neotropical migrant and resident bird species	41
6	Bird community diversity at Camp Shelby, MS: Diet-based guilds	41
7	Bird species diversity at Camp Shelby, MS: Foraging strata-based guilds	41
8	Bird community diversity at Camp Shelby, MS: General nest location-based guilds	42
9	Number of Federally listed TES plant species recorded based on LCTA plot and floristic inventory data for Fort Benning, GA	45
10	Mean Foliar Height Diversity (FHD) values by stand type and age class, loosely defined as communities, for Camp Shelby, MS	46
11	1992 land use summary for Fort Benning, GA	52

1 Introduction

Background

Early naturalists were impressed with the vast expanses of pine forest and diversity of native wildlife in the southeastern United States before extensive colonization and development by European settlers. J.F.H. Claiborne, while traveling through the longleaf pine forest of central Mississippi in the early 1800s, exclaimed both satisfaction and concern in his accounts.

Finer, straighter, loftier trees the world does not produce. For twenty miles at a stretch in places you may ride through these ancient woods and see them as they have stood for countless years The time must arrive when this vast forest will become a source of value (Riley 1906).

It is not clear whether Claiborne's use of the word "value" was in reference to economic value, ecological value, or both. It is certain, however, that the colonization and exploitation of the longleaf pine forests that Claiborne foresaw has had an exceptionally powerful influence in determining the plant and animal communities characteristic of the region today.

Military lands support diverse traditional military training and testing activities, some of which can be environmentally damaging. The lands also support an equally diverse and occasionally conflicting nonmilitary agenda consisting of threatened and endangered species (TES) conservation, grazing, fish and wildlife management, agriculture, recreation, mineral development, and archeological site preservation. Conservation and the military mission are not necessarily mutually exclusive. Many published reports serve to highlight the growing importance of Army training and testing lands in maintaining local and regional biodiversity. Lipske (1995) characterized Jefferson Proving Grounds, IN (targeted for closure under the base realignment and closure [BRAC] process) as:

surrounded by a patchwork of farms and small woodlots. The surplus military property is a massive forest island and a one time opportunity to shore up Mid-western biodiversity . . . the sort of large forest tract that is critical to the nesting success of warblers and other neotropical migrant birds.

Camp Pendleton, CA, represents one of the last relatively undeveloped areas on the southern California coast, with 17 miles of undeveloped coastline. This Marine Corps base supports the highest known density of nesting sites for the endangered California least tern (*Sterna antillarum browni*) and contains riparian sites supporting half the known nesting populations of the endangered least Bell's vireo (*Vireo bellii*) in North America (Boice 1992; Cohn 1995).

The lands of Fort Hood, TX, have been supporting military training requirements for two mechanized Army divisions for 20 yr, while maintaining significant breeding populations of two endangered bird species, the black-capped vireo (*Vireo atricapillus*) and the golden-cheeked warbler (*Dendroica chrysoparia*) (Tazik et al. 1992a). The largest known colony of Pallid bats (*Antrozous pallidus*) in the United States can also be found in a vacant Army storage building on the grounds of Fort Bliss, TX (Scott 1996).

Flather, Joyce, and Bloomgarden (1994) estimated that Department of Defense (DOD) lands support 26 percent of the listed threatened and endangered species, a disproportionally high number compared with its 9.7 million ha land base (24 million acres). Moreover, total numbers of TES on DOD lands exceed those on lands administered by the Forest Service, Bureau of Land Management, Fish and Wildlife Service, and National Park Service. As Army training lands begin to be commercially or privately developed under BRAC, the remaining installations will be faced with an increasingly important share of the management and conservation burden.

The Army's Integrated Training Area Management (ITAM) program is in the forefront of DOD efforts to identify and mitigate land management problems (Boice 1992). Under the ITAM umbrella, the Land Condition Trend Analysis (LCTA) program (Tazik et al. 1992b; Diersing, Shaw, and Tazik 1992) was developed as a means to inventory and monitor natural resource conditions on Army training lands, which total 5 million ha (12.4 million acres) worldwide (U.S. Department of the Army 1989). The LCTA program uses standard methods and permanent field plots, with the intent of providing data for multiple applications and upward reporting. Monitoring and mitigating environmental effects from training activities is important to the Army's responsibility as a public land steward, and it makes economic sense as well. In today's political climate, maintaining existing land is more practical than purchasing additional training land.

The framework for biodiversity conservation at the Federal level began to take shape with the National Environmental Policy Act (NEPA) of 1969. Currently, the importance of biodiversity both in the land management decision-making process and as a management objective is evident in the increasing number of legislative

efforts, professional society conferences, and workshops focused specifically on the topic. Guidance provided by Army Regulation (AR) 200-3 (1995) suggests that the measurement and conservation of biodiversity will concern Army natural resource professionals and trainers for decades to come.

Objectives

Conducive to realizing biodiversity objectives as stated in AR 200-3 (1995), the five primary objectives of this report are to:

1. Define and discuss the concept of biological diversity.
2. Provide a brief overview of the Army's LCTA program.
3. Identify current LCTA products, analyses, or methodologies that support the characterization of biodiversity on Army training lands in the southeastern United States.
4. Identify components of biodiversity that current LCTA products, analyses, or methodologies do not address.
5. Suggest potential enhancements or augmentations of current methodologies designed to address those deficiencies identified within the scope of the LCTA program.

Approach

Pertinent literature was reviewed to provide the conceptual background, working definition, regulatory framework, and factors known to influence biological diversity. Based on the literature, procedures and considerations for the analysis and interpretation of LCTA data with respect to characterizing biological diversity are given. A mixture of more traditional, quantitative measures of ecological diversity was identified, along with some more recent, descriptive approaches. In reviewing the LCTA program, a small degree of redundancy is apparent with Tazik et al. (1992b) in order for readers to understand the application of LCTA data and allow the report "stand alone." The authors used LCTA core plot data from several Army installations in the southeastern United States to support and illustrate the identified analyses. Data was checked for spelling errors and updated taxonomically. However, in terms of correct species identification, data was accepted as unflawed.

Scope

Although LCTA data used to assess biodiversity for this report were obtained from the southeastern United States, the overall concepts, approach, and analyses are applicable to any ecological region. This report is one in a series designed to provide installation data managers the necessary tools and background information to effectively summarize, interpret, and present their LCTA data. Specifically, Price et al. (1995) presents general univariate analyses of LCTA data and general guidelines for their interpretation; Anderson, Guertin, and Price (1996) investigates multivariate applications and the use of power analysis; and Schreiber et al. (unpublished report) summarizes LCTA data in the context of NEPA requirements. Senseman and et al. (1996) investigates the correlation between vegetative cover data and satellite-imagery-derived vegetation measures.

This report does not propose the use of a single standard measurement, monitoring program, or analysis technique for biodiversity assessment on Army training lands, nor does it propose the LCTA program be the sole basis by which installations address issues pertaining to biodiversity. Instead, this report identifies LCTA data as one of *many* potential data sources available to support Army land managers in quantifying certain aspects of biodiversity and in qualitatively addressing biodiversity issues in general.

Mode of Technology Transfer

It is intended that installation LCTA coordinators incorporate biological diversity considerations into future annual installation reports. This report will assist LCTA coordinators in developing additional installation-specific data summaries that meet local needs by identifying and discussing data summary considerations and limits of the LCTA field methods. Biodiversity considerations and data summaries presented in this document can be applied to integrated natural resource management plans, training land carrying capacity models, and NEPA documents required for military installations. Many of the summaries presented are intended to be incorporated into and automated by future versions of the LCTA computer system.

2 Biological Diversity

Defining Biodiversity

Arguably, biodiversity could be viewed more as a way of thinking rather than a quantifiable entity. Ecosystem parts and data summaries should not be thought of as autonomous pieces but as interdependent parts of a continually changing and oftentimes poorly defined puzzle. It is therefore no surprise that definitions of biodiversity and how we attempt to measure it are as variable as the concept itself. Biodiversity has been defined in broad terms such as "... the variety of life" (Biodiversity Task Force 1992) and "... the variety of life on planet earth" (Landres 1992), and "the variety of life and its processes" (AR 200-3 1995). While traditional measures of diversity focus on species richness and evenness, the current trend is toward the incorporation of functional attributes of ecosystems and the recognition of spatial and temporal scales. Towards that end, more comprehensive definitions of biodiversity have been suggested, such as "... the variety of life and its processes, including the variety of living organisms, the genetic differences among them, and the communities and ecosystems in which they occur" (USDI 1994). Despite the wording, these and many other published definitions implicitly agree that biodiversity does not simply mean the total number of species in a defined area. For purposes of this report, biodiversity is explicitly defined and hereafter refers to:

the sum of the representative biotic and abiotic constituents and assemblages, which exist at, but are not restricted to, genetic, species, ecosystem/community, and landscape levels, with each level containing highly interdependent and dynamic compositional, structural, and functional attributes.

"Representative" refers to a condition, species, or species assemblage that is characteristic of a specific habitat, ecosystem, or landscape. Note the lack of reference to time in this definition. Because ecological communities change over time, plant and animal species characteristic of an area at one point in time may not be characteristic of that area 100 years later. Alternatively, Balbach et al. (1995) defined "representative" for Camp Shelby, MS, as the set of conditions present before the arrival of European man (ca. 1740). While the need to place diversity in a time context is stressed, a "representative condition" is recognized as being a point floating along a continuum rather than as a fixed point in time.

Humans have the tremendous and unequalled capacity to selectively modify habitats, ecosystems, and landscapes, and because of this affinity are occasionally viewed as disjunct from nature. The purpose of this section is not to debate whether humans are natural components of the biodiversity puzzle or an extraneous force that mixes up the pieces. Rather, this section provides an overview of what biodiversity is and briefly discusses the major factors known to influence it.

Recognized Attributes of Biodiversity

Early naturalists believed disturbances were a major force in preventing ecosystems from achieving equilibrium or balance, while Solbrig (1991) echoes a currently held belief among many modern ecologists by asserting that disturbances should not be viewed “. . . as aberrations but as integral parts of nature.” Contrary to “balance of nature” references so widely made throughout the 19th and early 20th centuries, ecologists now surmise that most, if not all, ecosystems are not currently in or even striving towards a state of “balance” (DeAngelis and Waterhouse 1987; Solbrig 1991).

Discrete levels of diversity. Researchers (Angermeier and Karr 1994; Biodiversity Task Force 1992; Norton and Ulanowicz 1992; Noss 1990; O’Connell and Noss 1992; Odum 1994; and Hunter 1994) recognize the importance of scale in assessing biodiversity, advocating that a hierarchical approach is essential to adequately characterize biodiversity. Many researchers have even suggested that genetic, population (species), ecosystem (community), and landscape levels form the “standard” scales at which scientists should view and comparatively discuss diversity. *Genetic* diversity is the variety of genetic combinations, both genotypic (genetic makeup) and phenotypic (physical appearance), exhibited in a population. Maintaining genetic variability is essential because it allows populations to adapt to different or changing environments and promotes both individual and population health. *Species* (or population-level) diversity refers to the variety of species in an area and often integrates richness (number of species) and evenness (distribution) components. *Ecosystem* or *community* diversity is the variety of unique species assemblages that share a local environment. The size of that local environment is arbitrary and quite variable, ranging from part of an Army training area to the entire installation. Finally, *landscape* diversity considers the diversity and arrangements of many communities over broader geographic areas, which vary in size. Landscapes are clusters of interacting ecosystems repeated to form a heterogeneous land unit with a distinguishable structure (Forman and Godron 1981).

The importance of characterizing diversity at discrete multiple levels has been recognized for some time (MacArthur 1965), although Turner, Gardner, and O’Neill

(1995) argue that this approach is inadequate to address biodiversity issues on broad scales. Before the tremendous surge in "biodiversity" publications over the last decade, diversity at the population, community, and landscape levels had been referred to as Alpha, Beta, and Gamma diversity, respectively (Whittaker 1972; Karr 1976; Noss 1983; Sharitz et al. 1992).

Composition, structure, and function. Three fundamental attributes of biodiversity are composition, structure, and function (Franklin 1988; Crow 1989; Noss 1990; Waters 1994; Samson 1992; Sharitz et al. 1992; Hunter 1994). *Composition* has been a traditional, quantifiable measure of biodiversity and simply describes the number and abundance of species or other elements within an area. *Structure* is the three-dimensional arrangement of, within, and between the elements, such as the juxtaposition of plant communities or the shape of a rocky outcrop. *Function* refers to processes and relationships involving the composition and structural components (i.e., nutrient cycling, population turnover, and predation). All three attributes occur at, and should be considered at, each hierarchical level.

Factors Influencing Biodiversity

Biodiversity in the southeastern region is directly influenced by numerous abiotic (nonliving) and biotic (living) elements and processes, which include the properties and distribution of many soil types, proximity to the Gulf of Mexico, major river systems, mountains, deltas, fire frequencies, and climatic patterns. These factors all contributed to the development of the longleaf pine forests and other unique attributes of the region. The important influential elements and processes essential in developing and interpreting LCTA data summaries are briefly considered here.

Elements.

Abiotic: The array of nonliving components in the environment (i.e., the energy from the sun, synthetic pesticides and herbicides, elements [in the atomic sense], minerals, rocks, and geologic formations). Soil is a composite of the abiotic and biotic elements.

Biotic: The array of living components in an environment, from unicellular organisms to internal parasites to terrestrial and aquatic plant (vascular and non-vascular) and animal (vertebrate and invertebrate) species. A number of biotic groups are frequently singled out as being major contributors to, or influences on, biodiversity. These groups include threatened and endangered, introduced (exotic), endemic, keystone, indicator, and critical link species and are considered in more detail below.

Threatened and endangered species (TES): According to Martin et al. (1996), an estimated 158 animal and 121 plant species are Federally threatened or endangered in the southeastern region, of which 86 plant (71 percent) and 45 animal (28 percent) species occur on military lands. The growing list of candidate species for this region is even more impressive. Currently, there are 565 vertebrate and invertebrate animal species and 398 plant species listed as candidates for federal listing. TES issues often receive a disproportionately high amount of attention in biodiversity discussions although they comprise relatively small percentages of the flora and fauna. Nevertheless, an emphasis on TES can be justified because: (1) federal and state laws require it, (2) environmental groups often focus attention on TES, and (3) TES and other high-profile species can be useful tools in educating and redirecting public attention to many broader environmental issues related to biodiversity.

Introduced species: Generally, these are species that have been introduced into habitats, regions, or continents in which they previously did not occur. Echternacht and Harris (1993) report 50 vertebrate species as introduced in the southeastern region alone. The nutria (*Myocastor coypus*), a large aquatic rodent from South America, the house mouse (*Mus musculus*), common carp (*Cyprinus carpio*), European starling (*Sturnus vulgaris*), kudzu (*Pueraria lobata*), and purple loosestrife (*Lythrum salicaria*) represent just six of the many floral and faunal species introduced into the southeastern United States during the past two centuries. These non-native species are viewed by some as a major threat to the biotic integrity (Mooney and Drake 1986; Culatta 1991; Biodiversity Task Force 1992; Samson 1992; Angermeier 1994), many having been shown to displace or eliminate native species and even affect certain ecosystem functions. Moreover, Angermeier (1994) argues that an effective biodiversity conservation program should clearly differentiate at the onset between *native* and *artificial* diversity, placing all introduced species in the artificial category.

Endemic species: A species whose distribution is restricted to a specific geographic region. The gopher tortoise (*Gopherus polyphemus*), for example, is not only endemic to the southeastern United States, but its western population is threatened as well. Echternacht and Harris (1993) report 93 terrestrial vertebrate species as endemic to the southeast. Hardin and White (1989) estimate that the longleaf pine-wiregrass ecosystem in particular supports 66 rare, locally endemic plant species. Increasingly, it is being argued that the concept of biodiversity is only of value when applied to endemic species (Ratcliff 1986; Austin and Margules 1986; Harris and Atkins 1991).

Keystone species: A species believed to play a "key" or otherwise unique role in ecosystem stability or composition (Mills, Soule, and Doak 1993). Managing for keystone species positively influences biodiversity because management not only benefits the target species but also benefits all associated commensal and symbiotic species. The Federally threatened gopher tortoise, associated with sandy upland soils of the coastal plain, is an excellent example of a keystone species occurring in the southeast. Active and abandoned burrows of the gopher tortoise are known to be used by a minimum of 300 invertebrate and 60 vertebrate species, one of which is the Federally threatened Eastern Indigo snake (*Drymarchon corais*) (Auffenberg 1978; Eisenberg 1983; Speake 1986; Jackson and Milstrey 1989; Kaczor and Harnett 1990). Limited research suggests both Eastern Indigo snake abundance and total animal biomass are positively influenced as a result of gopher tortoise burrow presence in at least one area (Auffenberg 1978; Speake 1986). Thus, even a slight decrease in gopher tortoise numbers not only affects tortoise population dynamics but also has a considerable "ripple effect" throughout the community.

Indicator species: Species particularly sensitive to environmental perturbations that, by virtue of their presence in an area, indicate the presence of a certain environmental condition or stressor. While some researchers caution against the use of indicator species as the sole measure of ecosystem health, others acknowledge the potential for such species as a crude measure (Landres 1988; Noss 1989).

Critical link species: A relatively new term to identify those species that provide a critical role in ecosystem function, its total biomass or position in the food web being irrelevant (Westman 1990). For example, Westman (1985) cites some micro-organism decomposers, litter invertebrates, and plant pollinators as critical link species in certain ecosystems.

Processes.

Abiotic: Prominent geologic events such as the formation of the Rocky Mountains, the latest ice age, and lesser scale geological processes such as wind- and water-induced erosion and sedimentation of aquatic environments, continue to influence ecosystems today. Short-term changes in weather patterns and ocean currents (e.g., shifts in the jet stream and El Niño) and long-term trends (past ice ages and present global warming) can have profound influences on local and regional biodiversity. Abiotic events such as hurricanes, tornadoes, floods, fires, soil erosion, and sedimentation are important processes not only because they influence established communities but also because they can create a substrate for early successional communities.

Ecological succession: An environmental stressor-driven process by which ecosystems develop and evolve, frequently illustrated by a series of discrete stages, but often occurring as a continuum. Some well studied environmental stressors include water, nitrogen, fire, herbivory, and temperature. Taking a more traditional approach, Odum (1971) regarded ecological succession as an orderly process, both *directional* and *predictable*, resulting from the progressive modification of the physical environment by each community or seral stage.

Fire frequency: Noss (1988) wrote,

For certain ecosystems, such as longleaf pine-wiregrass communities in the southeastern United States, a disturbance measure as simple as fire frequency and seasonality may be one of the best indicators of biodiversity. If fires occur too infrequently, or outside the growing season, hardwood trees and shrubs invade, floristic diversity may decline, and key species may be eliminated.

Christensen (1981) estimated that the historical fire frequency across the southeastern Coastal Plain forests ranged between 2 to 8 yr, with a lower incidence of fires caused by lightning strikes when compared to more mountainous areas. Current management guidance on fire frequency varies depending on the specific plant community and whether TES or other species of concern are present. However, recommendations range from 1 to 5 yr (Platt, Glitzenstein, and Streng 1989; Allard 1990; Robbins and Meyers 1992; Martin 1992; Dunning 1993; Krusac and Dabney 1994; USACERL 1994a and 1994b).

Isolation: A state in which a subpopulation is separated from the larger population of which it was a part, either preventing or severely restricting genetic flow between the two groups and effectively reducing the genetic variability of the smaller group. Isolation typically occurs because of an abiotic event such as mountain formation, human-imposed physical barriers such as habitat destruction and fragmentation, or spatial barriers resulting from unusually long distance and otherwise chance dispersals. Darwin's finches (Lack 1947) represent a common scenario in which isolation of a population has led to speciation and an increase in regional biodiversity. Specifically, a small population of finches (family Fringillidae, subfamily Geospizinae) arrived on one of the Galapagos Islands after bridging a 750-km ocean barrier from South America, gradually colonizing each of the remaining islands. Because of the long inter-island distances, the original population of finches eventually evolved into 14 unique species (Lack 1947). Geographic separation of populations (allopatry) is perhaps the primary mechanism by which species have become isolated. However, Odum (1971) points out that sympatric speciation may be more important and widespread than previously believed. Odum (1971) cites

polyploidy (duplication of chromosome sets), asexual reproduction, and self-fertilization as potential mechanisms of genetic isolation in plant species.

Extirpation/extinction: Extirpation, in general terms, is a localized extinction. Many vertebrate species have been extirpated from much of their former range within the southeastern United States in this century, including the red wolf (*Canis rufus*) and cougar (*Felis concolor*). Extinction is unquestionably a natural process, and it has been generally recognized that approximately 99 percent of all known species are now extinct (Norton and Ulanowicz 1992). Solbrig (1991), in his discussion on the origin and function of biodiversity, maintains that "... the fate of every species is to become extinct eventually..." Most past extinctions have been the result of natural selection, an ecosystem process by which species possessing certain attributes or adaptations tend to persist, produce offspring, and adapt in a changing environment while others cannot compete or adapt and are lost. Throughout this century, however, the unparalleled and increased ability of humans to accelerate the alteration or elimination of ecosystem elements has clearly resulted in a rapid acceleration of the extinction rate at the global level, far greater than would be expected under natural selection (Myers 1979).

Movement patterns: Dispersal, or the one-way movement of organisms from an area, promotes range extensions and maintains genetic vigor of both individuals and populations. Emigration is the movement out of a previously occupied area and, depending on the size of the remaining population, can result in a decrease in biodiversity. Immigration, the movement into an area, can potentially increase biodiversity. Migration is a third type of movement that clearly influences biodiversity at the temporal (seasonal) scale but is also a major influence at the genetic and population level. Each mechanism has contributed greatly to the initial formation and continued maintenance of North American ecosystems. In fact, southeastern faunal diversity is largely the result of dispersal across the North Atlantic and Bering (Pacific) land bridge connections and continental movements during the Cenozoic Period (beginning approximately 65 million yr ago). With respect to freshwater fish species, Lagler et al. (1977) reports that 30 percent of North American species originated on the continent, 55 percent are of Eurasian origin, and 15 percent are of Central or South American origin. The Mississippi River Basin and the southeastern region in general are considered more diverse with respect to freshwater fish species than other regions on the continent (Lagler et al. 1977). Bird and mammal communities in the southeastern United States exhibit a surprisingly small South and Central American influence (e.g., nine-banded armadillo, porcupine) and show a much greater degree of similarity with European and Asian communities (Vaughan 1978; Welty 1982).

Habitat fragmentation, loss, and degradation: Fragmentation and alteration of the southeastern landscape have been, and continue to be, the driving factors in influencing biodiversity (Sharitz 1992). Fragmentation promotes the isolation of populations, encourages the dispersal of edge-associated species, and can result in the extirpation of area-sensitive species within the remaining fragments. Wilcox and Murphy (1985) emphatically assert that habitat fragmentation “. . . is the most serious threat to biological diversity and the primary cause of the present extinction crisis.” Gerard (1995) identified agriculture as the major factor in the loss of biological diversity and species abundance. The continued loss of tropical rainforests of South America and the old-growth forests of the Pacific Northwest is repeatedly cited in the media, tending to single out habitat loss as the primary force affecting biodiversity today. Habitat degradation may be less severe than its loss but, on a regional or global scale, probably impacts biodiversity to a greater extent than habitat loss. Degradation can occur if natural processes or events are suppressed (e.g., floods, fire), accelerated (e.g., erosion, sedimentation), or structural characteristics are altered (e.g., overstory or understory timber removal). Red-cockaded woodpecker and gopher tortoise habitat degradation, for example, has often been attributed, at least in part, to a reduction in fire frequency from that experienced in the early 20th Century (Hooper, Robinson, and Jackson 1990).

Hybridization: Hybridization is a natural process that can both increase and decrease genetic and species diversity, often simultaneously. Specifically, hybridization negatively affects biodiversity if one or both of the parental species are lost, while a positive effect occurs as the new hybrid is created. Two forest bird populations, the yellow-shafted flicker (*Colaptes auratus*) occurring in the western United States and the red-shafted flicker (*Colaptes cafer*) in the east, demonstrate a classic case of man-induced hybridization. The two flicker populations had been previously characterized as distinct species geographically separated by the adjoining grasslands of the great plains. However, extensive fragmentation of grasslands during the agricultural revolution of the 1800s largely removed this ecological barrier, allowing these subspecies to freely interact and extend their respective ranges. Subsequent hybridization became extensive enough that the yellow- and red-shafted flickers were no longer considered subspecies by many ornithologists, but collectively classified as “common” or “northern” flickers (*Colaptes auratus*) (Eisenmann 1973). Fragmentation of the Great Plains led to a similar hybridization between the Bullock’s oriole (*Icterus bullockii*) in the west and the Baltimore oriole (*Icterus galbula*) in the east, now collectively referred to as “northern” orioles (*Icterus galbula*) (Sibley and Short 1959).

The Regulatory Framework

Biodiversity and NEPA

The National Environmental Policy Act is a brief but commanding law that, among other things, requires Federal agencies to consider, evaluate, and publicly disclose all reasonably foreseeable environmental impacts from proposed actions. In Section 101(b) of NEPA (Public Law 91-190), one of the six stated environmental goals is “ . . . [to] preserve important historic, cultural, and natural aspects of our natural heritage, and maintain, wherever possible, an environment that supports diversity and variety of individual choice.” The NEPA mandate that Federal agencies use “ecological information” in planning and development is contained in Section 102(2)(H).

Army Regulation and Biodiversity

Section 11.1(1)(c) of AR 200-3, in contrast to implicit references found in NEPA, explicitly provides for biodiversity consideration by stating “It is an Army goal to systematically conserve biological diversity on Army lands within the context of its mission.” More specifically, AR 200-3 (Section 11-1(2)) identifies seven objectives that Army commanders and land managers should consider, to the greatest extent practicable, with respect to biodiversity:

- (a) Maintenance of viable populations of the nation’s native plants and animals throughout their geographic range
- (b) Maintenance of natural genetic variability within and among populations of native species
- (c) Maintenance of functioning representative examples of the full spectrum of ecosystems, biological communities, habitats, and their ecological processes
- (d) Implementation of management solutions that integrate human activities with the conservation of biological diversity
- (e) Increased scientific understanding of biological diversity and conservation
- (f) Public awareness and understanding of biological diversity
- (g) Encouragement of private sector development and application of innovative approaches to the conservation of biological diversity.

Biodiversity on the Political Agenda

The management trend among many Federal and state agencies now appears to be that which is more compatible with an ecosystem or biodiversity-based approach. The U.S. Forest Service, for example, is currently in the process of redefining policy, management practices, and goals for its national forests and grasslands to more closely reflect the importance of ecosystems (Thomas 1994; Robertson 1992). Similarly, both the U.S. Fish and Wildlife Service (USDI 1994) and Bureau of Land Management (USDI 1993) have also taken steps in this direction. The implications of ecosystem management for TES conservation for Army training lands have been investigated as well (Trame and Tazik 1995).

A bill recently introduced by Congressman James Scheuer (D-NY) would, among other things, initiate the development of a national biodiversity policy and conservation strategy (U.S. House of Representatives 1990). A related bill, introduced by Senator Mark Hatfield (D-OR) during the 104th Congress, would amend The Federal Land Policy and Management Act of 1976 to provide specifically for ecosystem management. The considerable confusion and debate that has arisen in recent times around the development, implementation, potential costs, and efficacy of ecosystem management and biodiversity conservation is somewhat expected. After all, managing entire ecosystems or even species assemblages is in marked contrast to the management practiced during the first half of this century. Habitat-level and single-species management for many Federal and state agencies was the standard during that period, and the emphasis on habitat interspersation to increase edge and enhance game populations was widely accepted and promoted.

3 The LCTA Program

Refer to Tazik et al. (1992b) for a comprehensive discussion of the LCTA program, its development, scientific basis, objectives, and specific field methods. However, because field methodology and types of data collected were integral considerations in determining the biodiversity characterizations presented in Chapter 4, a cursory overview of the LCTA program is provided.

Floristic Inventory

This significant short-term product of the LCTA program is a collection of all vascular plants occurring on an installation, with provisions being made for sensitive, threatened, and endangered species (see Johnson et al. 1993).

LCTA Plot Types

LCTA uses both core and special-use plots. Core plots are randomly allocated to eligible land cover (satellite imagery) and soil type (USDA soil map) combinations, called polygons, in a proportional manner based on total land area each combination occupies and the estimated maximum number of core plots. In contrast, special-use plot allocation is not a standardized process, with no minimum-size polygon or plot density standard.

Plot Inventory

Core plot inventories consist of four major elements: land use, line transect, belt transect, and wildlife sampling.

Land Use

This element is a documentation of recent military land use and maintenance activities and any evidence of wind or water erosion within the plot boundaries.

Line Transect

One point is measured along each 1-m segment of the 100-m line transect to quantify ground cover, canopy cover, and surface disturbance.

Belt Transect

This transect uses the line transect as its central long axis and extends 0.5 to 3 m on each side of the line. The purpose of the belt transect is to characterize species composition, density, and height distribution of woody and succulent vegetation and to monitor changes over time.

Wildlife Monitoring

Small mammal and songbird monitoring provides a minimal measure of terrestrial faunal diversity. They were selected because of their known suitability as biological indicators (Morrison 1986; Douglass 1989; Temple and Wiens 1989; Croonquist and Brooks 1991) and the relative ease in monitoring at the scale of the LCTA plot. Reptile, amphibian (herp), and medium-sized mammal surveys are recommended but considered optional (Tazik et al. 1992b; Diersing, Shaw, and Tazik 1992). Figure 1 portrays the spatial arrangement of wildlife surveys. For a discussion of specific field methods, see Tazik et al. (1992b).

Long- and Short-Term Plot Monitoring

Vegetation

Short-term monitoring is a reduced version of the plot inventory that is conducted annually but not designated for long-term monitoring. Ground and canopy cover are still estimated on the line transect, but identifying individual species is not required. Individual locations are not mapped on the belt transects; individuals are simply tallied by species into discrete height classes. Long-term monitoring is identical to the plot inventory with respect to the line and belt transect, but differs from the inventory in that plots are already established and, therefore, fieldwork proceeds more quickly and inexpensively.

Wildlife

Once the initial plot inventory has been completed, small mammal and bird surveys are conducted for two additional field seasons to establish a baseline data set. After

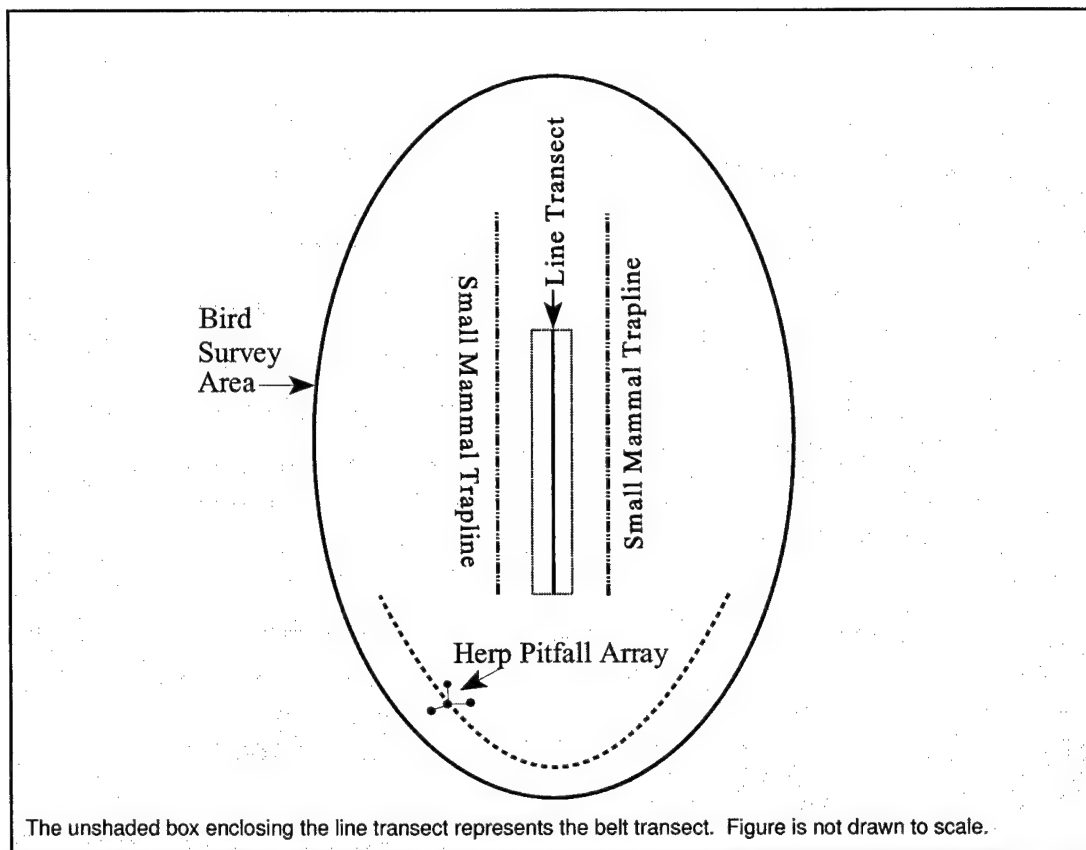


Figure 1. Spatial relationship of the LCTA bird survey area, small mammal transects, and optional herp pitfall array.

this period, plots are resurveyed for small mammals once every 1 to 3 yr, while annual surveys are conducted for birds. No differentiation is made between plot inventory and long-term monitoring.

4 LCTA Data and Biodiversity Characterization

General Overview: The LCTA-Biodiversity Interface

Many scientists agree on the fundamental components of biodiversity, yet few concur on how to define, quantify, monitor, and report them to allow for meaningful comparisons and interagency sharing of data. In spite of the difficulties, researchers (Noss 1983; OTA 1987; Ehrlich and Wilson 1991; Biodiversity Task Force 1992; Raven and Wilson 1992; Noss 1990; CEQ 1993; Colwell and Coddington 1994) have suggested various tools, analyses, and priorities to quantify biodiversity and provide the consistent and objective basis for its conservation across international, Federal, state, and agency boundaries. Spellerberg and Sawyer (1996) suggest using biodiversity standards and presenting a conceptual plan that incorporates monitoring procedures with biodiversity objectives. The treatment of biodiversity in this report largely follows that of Noss (1990), who identifies, and strongly advocates, the use of common indicator variables at relatively discrete hierarchical levels (Table 1). Many biodiversity elements and processes suggested for consideration are both ecologically significant and readily measurable. Scale is a critical consideration when interpreting LCTA and other ecological data and is commonly addressed from the spatial viewpoint although temporal considerations are known to be equally important in many instances.

To keep the focus on diversity and minimize semantics, this report supports Noss's (1990) existing approach rather than proposing an independent tract. It is recognized that not all scientists follow this approach. Angermeier and Karr (1994) provide a strong argument that ecological processes (e.g., mortality, productivity, soil erosion), regarded by Noss (1990) and others as components of biological diversity, are more appropriately regarded as a component of biological *integrity* (see Glossary). Angermeier and Karr (1994) further assert that biological *integrity* be characterized, monitored, and protected. It is therefore no surprise that no single inventory and monitoring program designed to address biodiversity at multiple scales has been widely accepted and used to date, nor, because of increasingly limited resources and political agendas, is it plausible that one will be developed soon. Many agencies and groups are reported to have biodiversity programs with contradictory mandates, approaches, and procedures (OTA 1987). Stohlgren and

Table 1. Matrix identifying indicator variables used in characterizing biodiversity at four hierarchical levels.

	Composition	Structure	Function
Landscape	Identity, distribution, richness, and proportions of habitat types and multipatch landscape types; Regional patterns of species distributions (endemism, richness)	Heterogeneity; connectivity; patchiness; patch size and configuration; juxtaposition; frequency distribution; perimeter-area ratio	Disturbance processes; nutrient cycling and energy flow rates; patch turnover rates; erosion rates; hydrologic processes; human land-use trends
Ecosystem	Relative abundance, frequency, richness, evenness, and diversity of species and guilds; proportions of endemic, exotic, threatened and endangered species; dominance/ diversity curves; life-form proportions; similarity coefficient; C3-C4 plant species ratios	Substrate and soil variables; slope and aspect; foliage density and layering; canopy openness; abundance, density, and distribution of key physical and structural features (cliffs, sinks, snags); water availability	Productivity; herbivory; parasitism; colonization and extirpation rates; nutrient cycling rates; human intrusion rates and intensities
Population	Relative abundance; frequency; importance or cover value; density	Dispersion; range; population structure (sex-age ratios); habitat variables; morphological variability	Demographic processes (fertility, mortality, survivorship, recruitment rate); metapopulation dynamics; population fluctuations; individual growth rates; adaptation
Genetic	Allelic diversity; presence of particular rare alleles; karyotypic variants	Effective population size; heterozygosity; Phenotypic and genotypic expression; heritability	Inbreeding depression; mutation rate; gene flow; selection intensity
Table modified from Noss 1990. Dark shaded cells represent common, light shaded cells more limited, and unshaded cells few if any applications of standard LCTA data.			

Quinn (1992), for example, found that no two national parks in California used the same classifications for seasonality and abundance in bird occurrences, nor did any two use the same census protocol. Agency goals and procedural differences in survey design, may be equally serious obstacles in evaluating biodiversity across landscapes.

In spite of the many ambiguities, general lack of coordination, and inconsistent guidance, installation natural resource personnel should strive to specifically address biodiversity in appropriate environmental documentation efforts because: (1) NEPA provides the Congressional mandate, (2) AR 200-3 unequivocally identifies biodiversity conservation as an important land management consideration, and (3) the public and many organized conservation groups have identified biodiversity as a significant issue that should be addressed in environmental impact assessment (Balbach et al. 1995).

One of the major, explicitly defined objectives of the LCTA program, as stated by Tazik et al. (1992b), is to characterize installation natural resources. LCTA data, while not being collected under a biodiversity assessment program exactly, represents a potential source of support in characterizing some of the recognized compositional, structural, and functional attributes of biodiversity (Figure 2). The degree to which LCTA data can characterize biodiversity at various scales is, in part, limited by the plot allocation process used on each installation. For purposes of this report, it is assumed that LCTA plots are allocated based on standard installation-wide stratification factors (see Chapter 3). Therefore, most of the analyses being presented are based on installation-wide pooling of data and reflect landscape-scale patterns. However, LCTA users do have the option of allocating special-use plots based on detailed vegetation (habitat) maps rather than maps based on unsupervised reflectance values and generalized soil maps (Tazik et al. 1992b). Special-use plots randomly allocated within biologically-meaningful communities identified through a supervised classification or aerial photo can increase the applicability of LCTA data to characterize biodiversity at the community/ecosystem and population level.

The primary objective of this chapter is to provide Army land managers a number of potential options when using LCTA data, analyses, procedures, or products to help characterize and monitor biodiversity issues unique to their specific installation and when addressing broader biodiversity issues raised by Army regulations and Federal and state regulatory agencies. First, consideration is given to the more traditional and statistical measures of diversity. The next three sections consist of more ecologically descriptive summaries supporting the characterization of the “discrete” yet interrelated components of biodiversity: composition, structure, and function.

Statistical Measures of Diversity

Alpha Diversity

Alpha diversity (α) is the biological diversity within a single habitat or community and has been historically treated as a composite statistic based on two distinct components of community composition: species richness and species evenness, which is the equitability of distribution of individuals

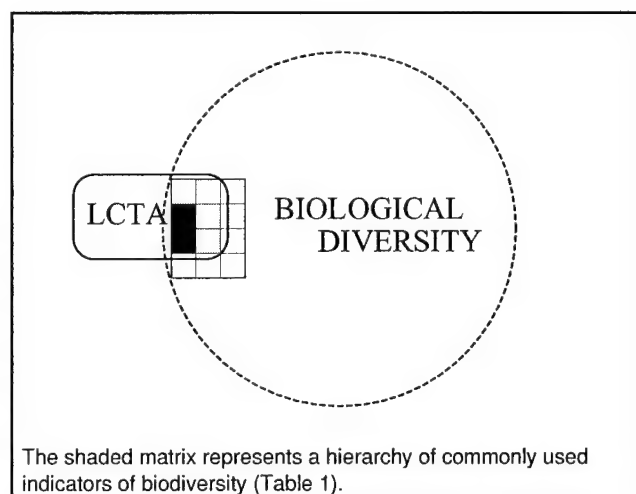


Figure 2. Conceptual diagram illustrating the degree of overlap between standard LCTA data and biodiversity characterization.

among the species. Numerous diversity indices can be found in the literature, and the following discussion is by no means an exhaustive account of the subject. Rather, the authors' intent is to briefly mention some of the more widely used, LCTA applicable analytical measures by which biodiversity has been quantified in the past. Refer to additional sources such as Peet (1974, 1975), Ludwig and Reynolds (1988), Magurran (1988), Pielou (1975), Waters (1994), Patil and Taillie (1976, 1979), and Steiner (1994) for more comprehensive discussions on the derivation, use, and interpretation of the various ecological diversity indices.

The convenience of addressing community structure with a single number undoubtedly contributed to the development and subsequent popularity of Alpha diversity indices. This convenience is tempered by Peet (1975), who cautions scientists not to overlook the assumptions and limitations of diversity indices, advising all indices are not appropriate for all ecological applications. Commonly used Alpha indices, or "within-habitat" diversity, include Shannon's (Shannon and Weaver 1949; also referred to as Shannon-Weaver and Shannon-Weiner), Simpson's (Simpson 1949), Fisher's α (Fisher, Corbet, and Williams 1943), Hill (1974), and Brillouin's (Brillouin 1956; Krebs 1989). These and other heterogeneity-based diversity indices generally differ in the degree to which they emphasize species richness relative to species evenness (Huston 1994).

Diversity indices provide limited information concerning overall community composition for a particular taxa of biota, and can be used as a common basis from which to compare areas or to monitor the same area for change over time. Originals and variations of Shannon's, Simpson's, and Fisher's indices are commonly used because the population size does not have to be known and the indices can be calculated from random samples. Each index assigns a value of zero to a community composed of one species. In contrast to Shannon's and Simpson's index, Brillouin's index is appropriate only for populations of known size and is used less frequently for that reason. Shannon's index and one derivation of Simpson's index are provided here.

Shannon's Index (Shannon and Weaver 1949):

$$H' = \sum \frac{n_i}{N} \log \frac{n_i}{N}$$

Reciprocal of Simpson's Dominance Index (Simpson 1949):

$$d_s = \frac{N(N-1)}{\sum n_i(n_i-1)}$$

where N is the total number of individuals and n_i is the number of individuals of the i th species in the sample.

Shannon's index is a measure of the average degree of uncertainty of predicting the species of an individual picked at random from the population. Thus, a habitat with a few evenly distributed species would have a lower index value than one with numerous species arranged in a random or aggregate pattern. The calculated value, or degree of uncertainty, increases as species become more evenly distributed and/or more species are added. Simpson's unmodified index (Simpson 1949), in contrast to Shannon's index, is commonly regarded as a measure of the probability that two individuals selected at random from a sample will belong to the same species. The greater biological intuitiveness of Simpson's index was espoused by Hurlburt (1971), who believed Simpson's index could be viewed as the probability of an interspecies encounter.

Adequacy of sample size is also a consideration when deciding upon the applicability of LCTA data for Alpha diversity analyses. In general, there are 200 randomly located core plots (points) on larger Army installations from which to obtain vegetative diversity data, 60 of which are also designated as wildlife plots (Tazik et al. 1992b). Warner, Brawn, and Heske (1996) found that surveying 20 of the 60 (33 percent) wildlife plots was sufficient to provide reasonably good Shannon diversity (H') estimates for small mammal communities. They recommend, however, that a sample size of 50 to 60 plots be maintained to produce a narrower confidence interval and greater statistical power. Warner, Brawn, and Heske (1996) further suggest that, for avian diversity, a minimum of 30 (50 percent) of all wildlife plots be surveyed to obtain reasonable estimates of richness and H' .

Table 2 (Rice, Hansen, and Demarais 1995) illustrates the application of LCTA data in characterizing diversity on military training lands in the more traditional, analytical fashion. When reviewing Table 2, several points are noteworthy. First, "ranking" habitats based solely on richness data would likely result in erroneous conclusions.

Table 2. Alpha diversity indices for LCTA small mammal and bird communities for two habitats on each of two Army installations in Texas.

Index ^a	Fort Hood		Fort Bliss	
	Savannah	Forest	Arroyo	Upland
Birds				
Species Richness	25	25	45	21
Simpson's ^b	9.5	9.1	11.3	5.3
Shannon's ^c	2.6	2.5	2.8	2.2
Small Mammals				
Species Richness	9	6	14	14
Simpson's ^b	5.6	1.9	5.5	7.7
Shannon's ^c	1.9	1.0	2.0	2.2

^a Table modified from Rice et al. (1995).

^b Reciprocal of Simpson's Dominance (Simpson 1949).

^c Shannon and Weaver (1949).

For example, two habitats on Fort Bliss contained the same number of small mammal species ($n=14$), but when considering equitability of distribution using the Simpson's and Shannon's indices, the upland habitat was regarded as more diverse. Second, while Shannon values are consistently lower than the corresponding Simpson values, both indices are in close agreement as to which habitat is more diverse with respect to both birds and mammals.

The LCTA user might find it desirable to statistically compare the same Alpha diversity index calculated for two habitats, ecosystems, or landscapes; the null hypothesis being that the two data sets are equally diverse. Brower, Zar, and Von Ende (1990) provide general calculations and cite appropriate references for making two-population comparisons using Simpson's and Shannon's indices.

Steiner (1994) recently considered which diversity index should be used by suggesting a reasonable approach is to choose two indices, one on each side of the spectrum, in addition to examining richness and evenness separately. This conservative approach is understandable given that the applicability and statistical validity of diversity indices in quantifying community diversity in a biologically meaningful way is not readily apparent in the literature. The number of observations per site and the number of sites per field season may be some of the most relevant considerations to the LCTA analyst selecting an index. Magnussen and Boyle (1995) assert that the "... statistical efficiency of the Shannon-Weaver index was so high compared to the efficiency of the Simpson index that it should be the preferred one." In fact, they found that testing the equality of two Simpson indices required a sample size about nine times greater than a similar test of two Shannon indices. Yet, Magnussen and Boyle (1995) and Pielou (1966) caution that Shannon's index assumes a complete census of the community or, if samples are taken, results in a biased estimate. The former is an extremely difficult assumption to satisfy while the latter may still be acceptable given logistical constraints associated with increasing the number of plots.

Moreover, many indices cannot be calculated if the majority of species are represented by one individual. Monk (1967) criticized Shannon's index as being insensitive to rare species, although analyses presented in Fager (1972), Whittaker (1972), Peet (1974), Brower, Zar, and Von Ende (1990), and Hunter (1994) suggest the inverse to be true. Huston (1994) asserts that, in situations where changes in relative abundance clearly indicate the effect of an important ecological process, it is appropriate to use an index such as Simpson's that emphasizes evenness over richness. Hunter (1992) also suggests that Simpson's index is less sensitive to changes in richness and places far too little weight on the less common and rare species in the population, thus introducing a potentially serious bias into the estimate. Steiner (1994) and Hunter

(1994) follow Peet (1974) in describing Simpson's index as being a measure of the relative dominance of a few species with high relative importance. Peet (1974) recommends the reciprocal of Simpson's index be used for general applications although Magurran (1988) and Kempton and Taylor (1976) report Fisher's α to be less affected by sample size. Finally, Patil and Taillie (1982) provide an alternative to these diversity measures, arguing that, in biologically diverse (species-rich) communities, the average species is relatively rare. Therefore, diversity should be viewed as "... the average rarity within a community." Their formal diversity equation and its mathematical basis are presented in Patil and Taillie (1976).

All of the widely reported and commonly used indices are too simplistic in that they address a few of the most easily measurable properties of ecological communities. A more fundamental issue may be their inability to satisfy underlying assumptions, such as the ability to select individuals at random from an infinite population (Simpson 1949; Ludwig and Reynolds 1988). Alpha diversity indices do little to help characterize or understand structural and functional attributes of biodiversity. The applicability of Alpha diversity indices to broadly characterize biodiversity is further reduced by focusing attention on more easily surveyed terrestrial biota such as plants, birds, small mammals, and herps. This reduction in biotic scale is regrettable; a constraint forced on the land manager by economic necessity. In spite of these obvious biases, Alpha diversity indices potentially have value as a means to quantitatively characterize compositional attributes of biodiversity if the underlying assumptions, data inputs, data outputs, and interpretive limitations are understood and clearly stated.

For the original question of which diversity index should be used by the LCTA analyst, many mathematical variants or "forms" of commonly used indices exist or have been proposed. A definitive discussion of the indices and their specific applications is difficult but, as a general recommendation, Magnussen and Boyle's guidance (1995) is followed in that logistical limitations such as sampling effort and expected sample size on many installations in the southeast tends to favor the use of Shannon's index over Simpson's. This recommendation is tempered by a quote from Huston (1994, p 64), who asserts that:

... far too much attention has been paid to comparison and criticism of **statistical** methods for quantifying diversity. This issue may be of interest to statisticians and mathematicians, but it has contributed virtually nothing to the ecological understanding of species diversity.

Beta Diversity

Beta diversity (β), variously referred to as "community similarity" or "species turnover," is an expression of the rate of change in species composition and abundance along an environmental gradient. In a simplistic sense, Beta analyses are a means of characterizing and discriminating ecological "uniqueness" (e.g., unique species assemblages, distributions, processes, and structure) of communities. Similar to Alpha diversity indices, Beta indices tend to emphasize different components on which they are based. Morisita's index of community overlap (Morisita 1959; Horn 1966), for example, weighs abundance over composition, while Sorensen's Coefficient of Community index (Sorensen 1949) weighs composition over abundance.

As with Alpha indices, the management implications of weighing rare species more heavily than common species should be a primary consideration in choosing a Beta index. Ludwig and Reynolds (1988), for example, recommend Jaccard's similarity index for computing resemblance when data consist of species presence or absence. Indices developed by Jaccard (1908), Pielou (1975), and Sorensen (Bray and Curtis 1957) are presented in equation form and followed by an example of their application to LCTA data sets (Table 3).

Jaccard's Index:

$$C_j = \frac{j}{a+b+j}$$

Percent Similarity (Pielou):

$$PS = 200 \sum \min(P_x, P_y)$$

Sorensen's Quantitative:

$$C_N = \frac{2jn}{aN + bN}$$

where P_x and P_y = numbers of species in communities x and y as proportions of all species in both x and y combined

j = the number of species common to communities A and B

a = the total number of species found in community A

b = the total number of species found in community B

jn = the sum of the lower of the two abundances recorded for both communities

aN = the number of individuals in community A

bN = the number of individuals in community B.

Table 3 (Rice, Hansen, and Demarais 1995) illustrates the application of LCTA data in characterizing community uniqueness on military training lands. When interpreting Table 3, note that the table is not a comparison of wildlife communities between Fort Hood and Fort Bliss. Instead, the values represent the degree of similarity between two habitats within the same installation. Thus, Table 3 indicates that both habitats sampled on Fort Bliss shared 100 percent of their small mammal species while 50 percent of the small mammal species were shared between two habitats on Fort Hood. In contrast to Fort Hood, relatively low Sorenson's values (C_N) for Fort Bliss indicate substantial variation in avian community structure (species richness and abundance) between the habitats. Additionally, the two habitats on Fort Bliss shared relatively few bird species (27 percent) while habitats on Fort Hood more closely approached complete similarity with respect to birds (84 percent). This finding suggests that, for the two habitats surveyed on Fort Bliss, the loss of one habitat would have greater negative implications on bird diversity than for mammals.

On a more landscape-level scale, consider a hypothetical Army installation broadly defined by four ecological communities in which all plant and animal species, species distributions, and species abundances are known. The size of each circle is in proportion to the total number of species it contains, while the position of each circle to each other indicates the proportion of species shared between the two communities.

From the subjective perspective of the soldier or technician in the field, hypothetical community D appears visually distinct, while the three other communities likely

would be perceived as a highly variable single community. A hypothetical Beta analysis confirms that community D has a Beta value of 0.00 when paired against A, B, and C. Further, a comparison of communities B and C results in a relatively high Beta diversity value (e.g., 0.92), a comparison of A and C has a moderate value of 0.50, and a comparison of A and

Table 3. Beta diversity indices for LCTA small mammal and bird communities for two Army installations in Texas.

Index ^a	Fort Hood	Fort Bliss
Birds		
Percent Similarity ^b	84	27
Jaccard ^c	0.72	0.37
Sorenson Quantitative ^c	0.99	0.60
Small Mammals		
Percent Similarity ^b	50	100
Jaccard ^c	0.25	0.75
Sorenson Quantitative ^c	0.94	0.78

^aTable modified from Rice et al. (1995).

^bValues can range from 0 (complete dissimilarity) to 100 (complete similarity).

^cValues can range from 0 (complete dissimilarity) to 1 (complete similarity). Values represent a comparison of two habitats within (not between) installations.

B has a low value (e.g., 0.19). To the installation land manager this suggests that, at least for taxa being considered along the two environmental gradients, community D is composed entirely of unique species relative to the other three; communities A and B have a low number of species in common, communities A and C have a moderate degree of overlap, and communities B and C exhibit a high degree of community overlap (see Figure 3).

Thus, the real value of Beta analyses in biodiversity characterization may be as a management tool in helping to quantitatively determine ecological "uniqueness" of communities present on an installation. Moreover, it provides a biodiversity-based approach by which to rank communities for receiving limited land rehabilitation and habitat conservation dollars. In this admittedly overly-simplistic case, and assuming the only issue was the conservation of unique species assemblages, community D would receive the highest conservation priority followed in descending order by communities A, C, and B.

Descriptive Measures: The Characterization of Composition

Not too long ago species richness was the single most widely used measure of ecological diversity. Richness is the most simple diversity index to quantify and is defined as the total number of species in an area at a point in time. LCTA richness data can be readily summarized at the scale of the installation (Figure 3; Table 4),

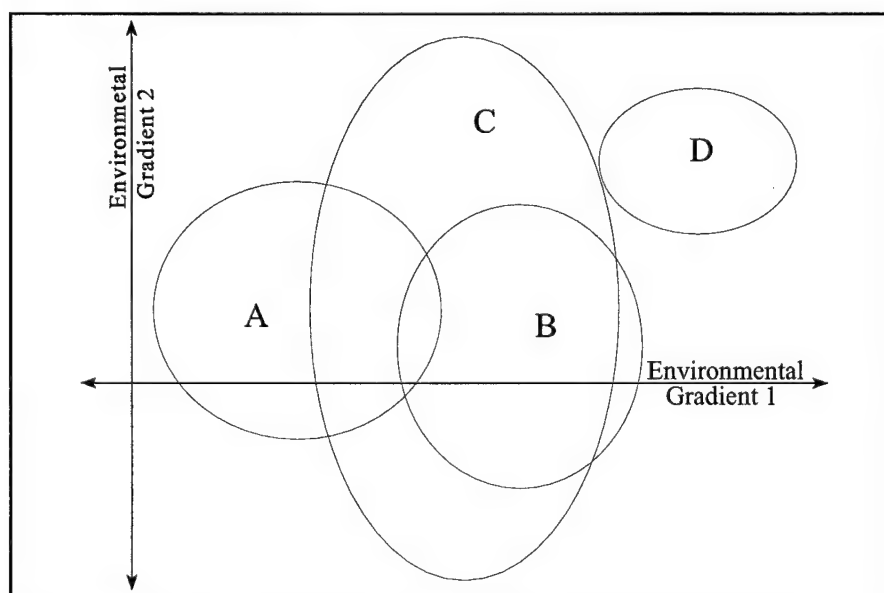


Figure 3. Graphical representation of community overlap between four hypothetical ecological communities along two environmental gradients.

Table 4. Floral taxonomic diversity (richness) values based on LCTA Floristic Inventory and LCTA plot data for three Army installations in the southeastern United States.

		Total Richness Based on LCTA Floristic Inventory and Plot Data (x)	Richness Based Only on LCTA Plot Data (y)	Percentage of Total Richness Represented on LCTA Plots ^a (y/x(100))
Fort Benning, Georgia ^b	<i>Families</i>	123	85	69.1
	<i>Genera</i>	402	198	49.3
	<i>Species</i>	807	404	50.1
Fort Stewart, Georgia ^c	<i>Families</i>	126	85	67.5
	<i>Genera</i>	437	207	47.4
	<i>Species</i>	1001	401	40.0
Camp Shelby, Mississippi ^d	<i>Families</i>	115	71	61.7
	<i>Genera</i>	357	176	42.3
	<i>Species</i>	698	314	45.0
^a Relative percent does not assume installation floristic inventories are 100 percent complete. ^b Fort Benning values based on 1991-92 data. ^c Fort Stewart values based on 1992-93 data. ^d Camp Shelby values based on 1990-1993 data.				

community (Table 2), and individual plot. LCTA richness is the qualitative counterpart of species richness, the species checklist, and symbolizes an elementary but essential piece of the biodiversity puzzle (Bogan, Finley, and Petersburg 1988; Price et al. 1995).

Documenting all species in an area is often an explicitly or implicitly stated objective in many inventory and monitoring programs. Assuming it was economically feasible (generally a poor assumption), attaining this goal would be a significant research accomplishment indeed. However, ecologists caution that, even if accurate richness values could be obtained, by themselves they have limited value. To quote Noss (1990), "knowing that one community contains 50 species and another contains 500 species does not tell us much about their relative importance for management purposes." Rather, it is the life history attributes associated with each species that can be more effective in describing the uniqueness of biological assemblages present on an installation and can be incorporated into the more biologically interesting comparisons and summaries. Several alternative approaches to addressing composition-related indicator variables of diversity have been proposed that clearly are more descriptive than traditional. From these approaches, a single statistic

(value) is generated. LCTA data can potentially support three of these approaches: taxonomic, trophic, and ecological guild-based measures of diversity.

Taxonomic Diversity

Table 4 shows the first measure, which considers taxonomic diversity as a function of species richness. Prance (1994) defines taxonomic diversity as the number of orders, families, genera, and species represented in an area. An important consideration to remember when interpreting taxonomic diversity (Table 4) is that only *total numbers* are compared; nothing should be assumed regarding species similarity between the floristic inventory and plot data. That is, some species and/or families are recorded only on the plots, some are only on the floristic inventory, and some are common to both. This issue has particular significance with respect to monitoring and is discussed in greater detail later (see p 36) in this chapter. Installation land managers might find certain groups within a taxa (families, genera, or species) particularly sensitive to environmental stressors or habitat change and thus especially promising as potential indicators of diversity loss.

Quantifying taxonomic diversity at the level of the installation is a matter of querying the LCTA floristic inventory, core plot, and special-use plot databases and creating a third list of all unique species codes. The completeness of the total checklist is an important consideration when interpreting Table 4. How accurately an integrated list represents what is currently on the installation may take several years to ascertain. Clearly, however, the total list will give a more accurate portrayal of the installations diversity than either the floristic inventory or the plot data alone. The importance of a comprehensive species checklist was discussed in Price et al. (1995) but, by itself, provides only a "one dimensional" picture of an installation's biological diversity.

Characterizing biodiversity on an installation, in a sense, means describing variety. Describing variety need not require the large-scale collection of additional new data sets but can simply be a matter of adjusting the scale ("repackaging") of currently collected data to view diversity as the multidimensional entity that it is. LCTA data allow for analytical summaries such as relative abundance, diversity indices (Alpha/Beta), and richness totals in addition to more qualitative or descriptive summaries. Calculating species dominance (Odum 1971)—a measure of species composition *and* abundance—would be a logical followup summary to quantitatively describe a particular wildlife or woody plant species relationship with others on individual plots or within communities.

Often, the LCTA data collection process begins with the floristic inventory (Tazik et al. 1992b). Although intuitively expected, LCTA floristic inventories should not be assumed to be 100 percent complete. An analysis of the Fort Benning data (Figure 4) reveals that 22.1 percent of the species were unique to LCTA plots, while the remainder of the species documented (in agreement) were documented by the floristic inventory. This statistic further suggests the floristic inventory was, at a conservative estimate of completeness, 77.9 percent complete.

In contrast to Fort Benning, 13.3 percent of recorded plant species were unique to the LCTA plots on Fort Stewart (Figure 5), indicating the floristic inventory was, at best, 86.7 percent complete. Maximum completeness is often a desired goal but considered unreachable because of the high probability that one or more species will not be detected through the LCTA floristic inventory or individual plot surveys. Thus, when quantifying composition-related aspects of diversity at the scale of the installation (landscape), limitations of the LCTA subcomponents supplying data (floristic inventory, core and special-use plots) clearly need to be recognized. Limitations are, in a sense, user-defined—a function of the resources available to the installation. If additional resources become available, perceived deficiencies in monitoring can be mitigated by increasing the number of core and special-use plots. At a minimum, however, Figures 5 and 6 suggest the standard core plot allocation provides a check on the completeness of the floristic inventory, especially in the early years following LCTA implementation. Special-use plots, in contrast to core plots, potentially can pick up a greater proportion of rare or uncommon species found on the installation but often lack the long-term monitoring commitment. Second (and more importantly), the figures indicate that although LCTA core plots are a significant source of presence data, only a fraction of the known species

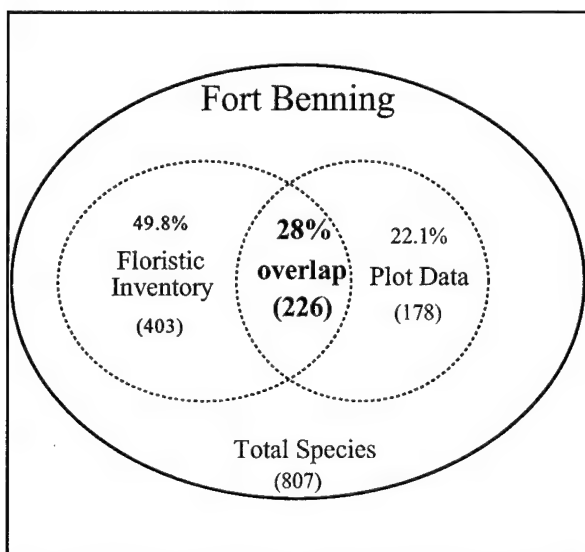


Figure 4. Number of unique and shared species between the LCTA Floristic Inventory and 1992 Plot Surveys for Fort Benning, GA.

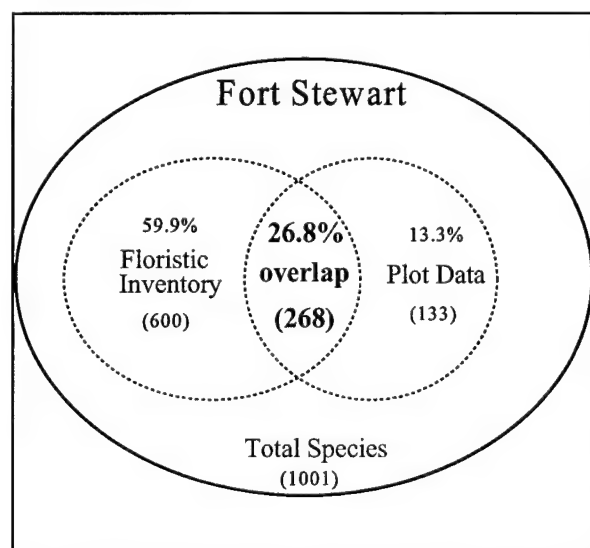


Figure 5. Number of unique and shared species between the LCTA Floristic Inventory and 1992 Plot Surveys for Fort Stewart, GA.

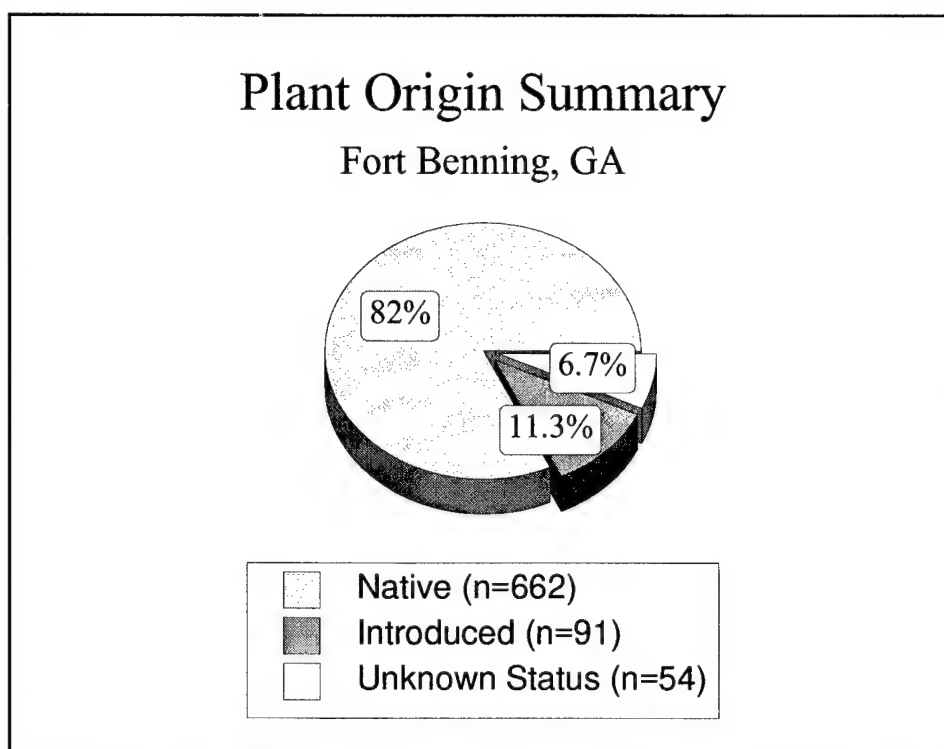


Figure 6. Fort Benning plant diversity—ratio of native to introduced plant species based on 1992 LCTA plot data.

occurring on an installation are being monitored annually. If the two examples provided are indicative of southeastern installations as a whole, this fraction falls between 40 to 50 percent.

Knowing the limits of the plot data is especially important when *monitoring* biodiversity because LCTA monitoring is based solely on core plot data, and quantifying the floristic inventory/plot overlap is a necessary step in defining the limitations (Figures 4 and 5; Table 4). Table 4 suggests that for Fort Stewart, approximately 68, 47, and 40 percent of the families, genera, and species, respectively, are being monitored via the LCTA core plots. For Fort Benning and Camp Shelby, approximately 50 and 45 percent, respectively, of the total species richness was being monitored on the plots, with family and genera percentages similar to that of Fort Stewart.

Trophic Diversity

A second interesting and potentially informative approach to characterizing biodiversity within communities is provided by Yodzis (1993). In contrast to the ecological guild concept in which species groupings are based on the resource(s) being used, "trophodiversity" assessments are based on an ecological food-web theory (Yodzis 1993). Specifically, species that have the same predators and prey are

considered trophically indistinct. All species in the community are grouped, and groups can consist of one species. Yodzis (1993) considers these aggregate groups or "trophospecies" the most basic building block in the development of a "legitimate" community food web. Trophospecies are linked to other trophospecies based on their trophic relationships, forming food *chains* of varying lengths that interconnect to form the community food *web*. Thus, depending on the level of information available to the land manager, there are many options to express trophodiversity quantitatively such as: (1) the total number of trophic links (trophospecies to trophospecies) in a community food web, (2) the mean length of each food chain (number of links), and (3) the mean number of food chains.

Researchers question whether the quantification of trophodiversity is an appropriate application of LCTA data. Many conceptual and technical difficulties have hampered widespread acceptance and application of this concept to "real" communities. Most fundamental perhaps is the difficulty in delineating the boundaries of a community in an ecologically meaningful way. Secondly, a lack of taxonomic and life-history data for many species, especially invertebrates and microorganisms, makes the grouping of trophospecies difficult. Finally, there is a lack of consistent protocol for aggregation into trophospecies. Prey "switching" and related behaviors occur in a community because of season and species life-cycle requirements, thus the problem of how to address (quantify) the *strength of connections* within and between food chains. Thus, all data requirements for trophodiversity assessment are not readily available from LCTA at present. For biodiversity characterization, it may be more cost-effective to focus on *trophic guilds* (Huston 1994) or other guild-based indicator groups.

Guild Concept-Based Diversity

The application of guild concept in classifying terrestrial vegetation (Johnson 1986) has been widely accepted for some time, with bird (Severinghaus 1981; Szaro 1986; Verner 1984), small mammal (Brown and Heske 1990), and reptile (Jones 1981) applications becoming more prevalent in the literature. Commonly presented plant species guilds include growth-form (tree vs. shrub, grass vs. shrub), leaf persistence (deciduous vs. evergreen), mode of dispersal (wind vs. animal), and life-form (annual vs. perennial). Arguably, wildlife guilds are more difficult to define in a biologically meaningful way than plants, but common animal applications include what trophic level a species occupies, where it lives, how it moves, if it migrates, how it obtains its food, how long it lives, how it reacts to environmental stress, its reproductive strategy, what structural form it has, and its geographic region of origin. Installation-wide summaries were generated by merging the floristic inventory and plot databases and are provided as real-life examples of how LCTA data support the characterization of

the composition attribute (landscape scale) of biodiversity. Note that a particular species can belong to more than one guild, since membership in a guild depends on the resource being considered, the time of year, and the life-cycle stage.

Figure 6 indicates that, at Fort Benning in 1992, the total number of native plant species exceeded introduced species by approximately a 7:1 ratio. Note that this figure does not address abundance; that is, it does not suggest that there are seven individuals of a native species for every one individual of an introduced species. For calculating dominance (Odum 1971), an index that considers both richness and relative abundance of each species would be an additional application of the plot data, if clarifying the potential impacts of introduced species on community composition or on a particular site were desired.

Figure 7 indicates that, at Fort Benning in 1992, the number of perennial plant species (not individuals) on the installation exceeded annuals by approximately a 5:1 ratio. The number of species with an unknown status (n=52) is an example of a known discrepancy in the current database.

Figure 8 indicates that most plant species (not individuals) documented on the core plots at Fort Benning were forbs, followed distantly by grass and tree species. This ratio is not unexpected in southern forests managed in part or whole for timber production and further reinforces the importance of forbs in maintaining growth

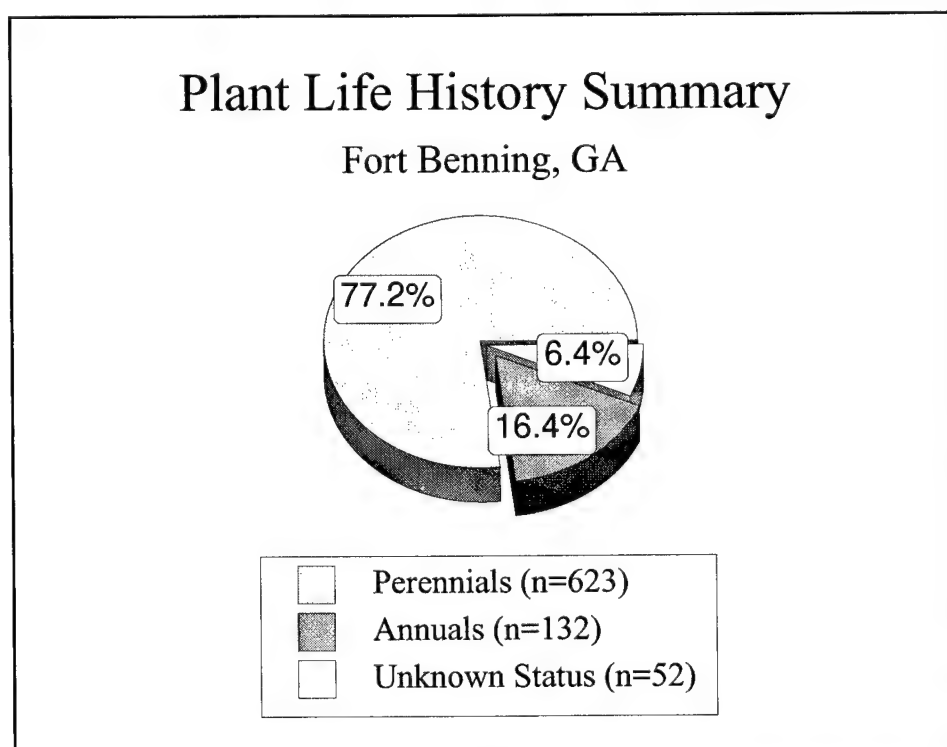


Figure 7. Fort Benning plant diversity—ratio of annuals versus perennials based on 1992 LCTA plot data.

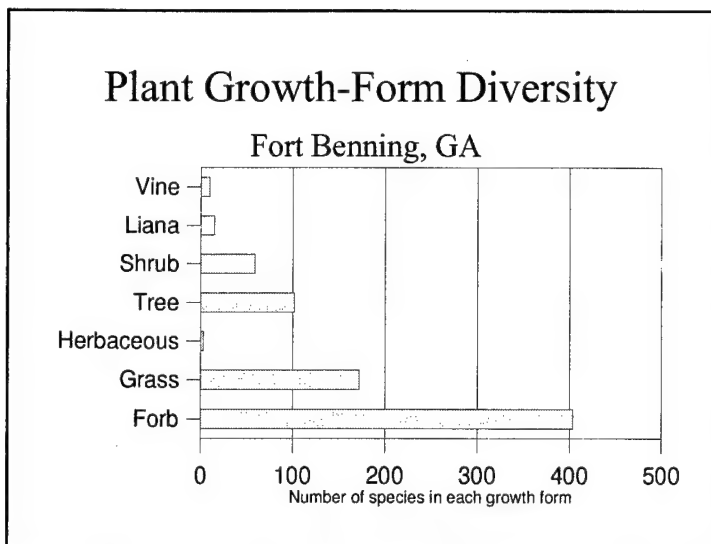


Figure 8. Fort Benning plant diversity—growth form summary based on the LCTA floristic inventory and 1992 plot data.

form diversity at Fort Benning. Additional life form summaries include the breakdown of grass species by C3/C4 status. Even though this status is a potential application, information is not available in current LCTA documentation but could be added by installation personnel.

Descriptive summaries often focus on grouping species based on how they use a resource (guild) in a community. Guild analysis facilitates community study by

reducing the number of components being considered. Secondly, guilds represent a management link tying a species to a measurable resource (Landres 1986). Credit for the original development of the guild concept has generally been given to Root (1967), who defined a guild as a group of species that exploits the same class of environmental resources in a similar way. However, this study follows Landres (1986) in that for management purposes, a guild is defined simply as a group of organisms that use a similar resource. The resource being used can be very general or quite specific and can vary in time and space. Animal and plant guilds are defined, in part, by their life history attributes, many of which can be found readily in the literature.

Cross-referencing overall LCTA species lists with their associated life history attributes can provide biodiversity-relevant information on many composition indicator variables at the landscape level (Table 1). When characterizing avian community diversity on an installation, some of the more common guild-based applications of LCTA data include migratory status (Table 5), principal diet (Table 6), feeding location or stratum (Table 7), and general nest location (Table 8). Primary foraging technique is another way of addressing bird diversity, with common classifications including gleaners (ground, bark, or foliage), foragers, probers, hawkers, and divers. Ehrlich, Dobkin, and Wheye (1988) provide definitions and discussion on these and other foraging techniques in their birding handbook. Note that, although these types of summaries are, to a small degree, an index of functional redundancy within a community (Walker 1992), LCTA data by itself cannot: (1) ascertain whether a community is functional, (2) identify the minimal level of redundancy required to maintain the biological integrity of the ecosystem, or (3) identify what level typifies the community.

Table 5. Bird community diversity at Camp Shelby, MS: Total number and frequency of neotropical migrant and resident bird species.

Migratory Status		0-10 Year Old Longleaf Pine (n=9 plots; 43 species; 326 individuals)				50-70 Year Old Longleaf Pine (n=15 plots; 49 species; 521 individuals)			
		Species # %		Individuals # %		Species # %		Individuals # %	
<i>Neotropical Migrant*</i>	Class A	19	0.442	153	0.469	23	0.469	216	0.415
	Class B	8	0.186	70	0.215	7	0.143	59	0.113
<i>Resident**</i>		16	0.372	103	0.316	19	0.388	246	0.472

Note: 1991-92 LCTA data; table based on data provided in Balbach et al. (1995).
 *Neotropical Migrant classes defined by Partners in Flight (1991).
 ** May include some short-distance, non-neotropical migrants.

Table 6. Bird community diversity at Camp Shelby, MS: Diet-based guilds.

Principal Diet	0-10 Year Old Longleaf Pine (n=9 plots; 43 species; 326 ind.)				50-70 Year Old Longleaf Pine (n=15 plots; 49 species; 521 ind.)			
	Species # %		Individuals # %		Species # %		Individuals # %	
<i>Omnivore</i>	27	0.628	215	0.66	23	0.469	346	0.664
<i>Insectivore</i>	24	0.558	168	0.515	26	0.531	275	0.528
<i>Granivore</i>	5	0.116	40	0.123	5	0.102	23	0.044
<i>Frugivore</i>	3	0.07	6	0.018	3	0.061	20	0.038
<i>Carnivore</i>	1	0.063	3	0.01	6	0.122	8	0.015
<i>Herbivore</i>	1	0.023	2	0.01	1	0.02	1	0
<i>Crustaceovore</i>	0	0	0	0	1	0.02	1	0

Note: 1991-92 LCTA data; values indicate totals.

Table 7. Bird species diversity at Camp Shelby, MS: Foraging strata-based guilds.

Foraging Strata	0-10 Year Old Longleaf Pine (n=9 plots; 43 species; 326 ind.)				50-70 Year Old Longleaf Pine (n=15 plots; 49 species; 521 ind.)			
	Species # %		Individuals # %		Species # %		Individuals # %	
<i>Air</i>	5	0.116	25	0.08	11	0.224	48	0.09
<i>Upper Canopy</i>	7	0.163	50	0.153	7	0.143	85	0.163
<i>Lower Canopy</i>	16	0.372	133	0.408	16	0.327	245	0.47
<i>Bark</i>	5	0.116	43	0.132	5	0.102	96	0.184
<i>Floral</i>	1	0.02	3	0	1	0.02	1	0
<i>Ground</i>	20	0.465	156	0.479	22	0.449	265	0.509
<i>Shoreline</i>	1	0.02	1	0	0	0	0	0
<i>Water</i>	0	0	0	0	2	0.04	3	0

Note: 1991-92 LCTA data.

Table 8. Bird community diversity at Camp Shelby, MS: General nest location-based guilds.

Nest Location	0-10 Year Old Longleaf Pine (n=9 plots; 43 species; 326 ind.)				50-70 Year Old Longleaf Pine (n=15 plots; 49 species; 521 ind.)			
	Species # %		Individuals # %		Species # %		Individuals # %	
<i>Upper Canopy</i>	5	0.116	59	0.181	11	0.224	113	0.217
<i>Cavity</i>	10	0.233	31	0.1	12	0.245	87	0.167
<i>Lower Canopy</i>	23	0.535	189	0.58	19	0.388	285	0.547
<i>Cliff</i>	0	0	0	0	3	0.06	5	0.01
<i>Man-made Structure</i>	2	0.05	10	0.03	3	0.06	12	0.02
<i>Ground</i>	9	0.209	98	0.301	8	0.163	99	0.19
<i>None (nest parasitizer)</i>	1	0.02	2	0	1	0.02	1	0
Note: 1991-92 LCTA data.								

Note when reviewing Tables 5 through 8 that the primary focus of these tables is on a broad-brush characterization of within-community diversity rather than a comparison of two communities. Data collected from LCTA plots within two seral representatives of longleaf pine are presented simply to show community variability (in terms of species richness) and to highlight the desirability of having all seral stages represented in the plot allocation process. As inferred in earlier discussion, logistic and economic constraints make it unlikely that an adequate number of plots will be allocated at all the various seral stages of communities, resulting in the general tendency for LCTA data to be summarized at broader scales. Finally, because the sampling effort between the two seral stages is markedly different in these situations (15 vs 9 plots), the installation may want to consider the mean number per plot as a basis for comparison rather than simple totals.

With specific reference to Tables 6 through 8, bird species were assigned to guilds based on primary *and* secondary tendencies. Thus, each species was associated with a minimum of one and a maximum of two guilds. For this reason, percentage totals for the *species* and *individuals* columns exceeded 100 percent. For a less confusing or "cleaner" summary, assign species to guilds based only on primary tendencies.

Table 5 summarizes the diversity of bird life during the spring and early summer period on Camp Shelby, based on species migratory tendencies. For this particular guild application, membership within a group is mutually exclusive (columns add up to 100 percent). The data indicate that, for this survey period, Neotropical Migrants, as a group, represented a greater source of species diversity than resident birds. Considering the three subgroups, Class A or "true" neotropical migrants are the most dominant in terms of richness. True neotropical migrant species breed

entirely in North America and winter south of the United States. Class B migrants contribute from 14 to 19 percent of the species. These migrant species generally breed and winter in the United States, but have some populations wintering south of the United States. Resident and short distance migrants contribute about 38 percent of the species regardless of community type but appear to achieve greater relative abundance in the more mature pine stands (mean of 16.4 per plot vs 11.4 per plot). While bird surveys are most often conducted during the breeding season, diversity should be considered throughout the year because: (1) military training occurs throughout the year, and (2) the contribution of resident species vs. migrant species (in terms of diversity) changes markedly during the nonbreeding season.

Table 6 is a summary of the diversity of birds on Camp Shelby; principal diet being the environmental resource used to group the species. A relatively high degree of functional redundancy is indicated for only two guilds: omnivores and insectivores. The remaining five groups are represented by considerably fewer species and individuals, some of which are actually secondary tendencies of species found in the top two guilds. This outcome is somewhat expected, however, considering how broadly most scientists define dietary tendencies. In most guilds, the midsuccessional (50 to 70 yr) habitat appears superficially to support greater total numbers of individuals than early successional (0 to 10 yr) habitats. Upon closer examination, this discrepancy may be more appropriately attributed to differences in sampling bias, for when considering abundance based on the overall mean number of individuals per plot, the early (48.2/plot) and late (44.9/plot) seral stages are virtually indistinguishable.

Redundancy within avian foraging guilds (Table 7) is more evenly distributed in the spatial sense (strata, not habitat) than was evident in the diet-based approach. Most of the terrestrial strata are well represented with the exception of the aquatic guild. The relative paucity of aquatic feeders is expected and probably attributed to a large degree to the core plot allocation process, which, at present, is biased towards spring and early summer species associated with terrestrial communities. Less obvious is the lack of floral feeders (hummingbirds), although this may be a reflection of bias as well (e.g., surveyor skill, chance, local activity, and weather).

Lastly, Huston (1994) advocates an approach that combines analytical and guild-based concepts into a classification for characterizing community diversity. He defines total species diversity as the number of functional groups in a community multiplied by the average number of species per functional group. Functional groups are based on resource use and defined in relatively broad terms such as trophic levels, guilds, and plant life forms. Explaining the specific resolution depends on the component or aspect of diversity being addressed. Two premises

behind Huston's approach are: (1) factors that influence the number of functional groups are different from factors influencing the number of species within a group, and (2) functional groups do not respond to environmental change in the same way. Higher numbers of species within groups (i.e., analogous species) can contribute to greater ecosystem integrity and community stability (resistance and resilience) in response to an environmental perturbation (Walker 1992).

Threatened, Endangered, and Sensitive (TES) Species

Installation biologists can fully characterize biological diversity on their installation only after identifying what is *not* on their installation. To clarify this statement, return to the original definition of biodiversity, "... the sum of representative biotic and abiotic constituents and assemblages . . ."; the key word being "representative." NEPA does not provide a set of minimum numbers that, if achieved, affirms that representative species or species assemblages exist. However, many state natural heritage groups have developed ranking systems that can assist land managers in more quantitatively assessing the importance of species occurring on their installation relative to the state, region, and nation. This multiscale approach indirectly addresses the issue of representativeness by giving higher rankings to endemic species and lower rankings to species with broader distributions.

Some species in the southeast tend to be threatened and endangered because of habitat loss, narrow habitat or life-cycle requirements, low reproductive potential, high sensitivity to human or environmental disturbance, or a combination thereof. Because LCTA core plots are allocated based on relatively coarse-scale environmental strata located in habitat "patches" of five acres or more, it is highly unlikely that an adequate number of plots will fall in all TES areas. TES often have a high specificity for particular habitat type, and two or more TES can occur on an installation. The standard plot allocation process clearly limits the applicability of using core plot data in addressing many TES issues. Consequently, most installations find it necessary to augment the core plot allocation with TES-specific special-use plots. Table 9 indicates that on Fort Benning, five Federal threatened and endangered plant species were documented with LCTA methods. In this particular case, 40 percent (two of five) of the TES were found on core plots. Not addressed in Table 9, but equally important, is the need to address state-listed species and sensitive, rare, and other species of concern. Even though LCTA core plots may not be very useful for TES, the floral inventory was designed to specifically address TES plant concerns.

Table 9. Number of Federally listed TES plant species recorded based on LCTA plot and floristic inventory data for Fort Benning, GA.

Status	LCTA Documentation of TES	
	Total Number Recorded in Floristic Inventory	Number Recorded on Plots ^a
Threatened	0	0
Endangered	1	1 ^b
Candidate	4	2
^a All species found on plots were previously recorded in the floristic inventory.		
^b Occured on a special-use plot.		

Descriptive Measures: The Characterization of Structure

Structure is a characteristic exhibited by plants, animals, soil, and all abiotic land-forms comprising the landscape and has long been recognized as an important attribute of ecosystems. Vegetative structural diversity is often addressed in the context of its vertical and horizontal subcomponents, both of which clearly are major factors in predicting the diversity of animal species that will be present in an area (Leopold 1933; Kendeigh 1961; West and Allen 1971; Odum 1971; Forman and Godron 1981; Short and Burnham 1982; Cooperrider, Boyd, and Stuart 1986; Wilson 1988; Sharitz et al. 1992). One variable needed in determining the amount of horizontal structure in an area is density, but it is not collected on most LCTA core plots. Plant density for any woody species on the standard 600 m² LCTA belt transect, if recorded, could easily be converted to plants per ha (10,000 m²) by multiplying the absolute number of individuals observed by 16.67. Shannon and Weaver (1949) provide the analytical basis and a discussion on two common horizontal diversity (patchiness) and Foliar Height Diversity (FHD) indices. More specifically, FHD is an index of how the vegetation structure along a transect is distributed within discrete vertical layers while patchiness describes the regularity of vegetation in the horizontal plane. Density is a primary input into both habitat patchiness and FHD indices, and is generally based on measured plant distances from the transect.

Cooperrider, Boyd, and Stuart (1986) present a simpler method for calculating FHD and patchiness when measured distances are not taken. Using presence/absence data at various vertical positions or "layers" over the transect, FHD (Table 10) and patchiness is calculated based on the proportion of total points at which foliage occurred. Vertical layers are user-defined, the number of layers ranging from one combined layer to numerous discrete layers. Because lateral distances and individual counts are often lacking, this method may be more applicable for installations using LCTA data to help describe their plant communities. When interpreting Table 10, note that stand types and age classes were loosely defined as discrete

Table 10. Mean Foliar Height Diversity (FHD) values by stand type and age class, loosely defined as communities, for Camp Shelby, MS.

Stand (community) Type	Age Class (yr)	FHD
Longleaf Pine	5-10	1.30684
Longleaf Pine	20-30	1.59199
Longleaf Pine	30-50	1.46185
Longleaf Pine	70-100	1.72175
Slash Pine	20-30	1.50347
Slash Pine	30-50	1.73649
Slash Pine	50-70	1.42789
Loblolly Pine	10-20	1.72282
Loblolly Pine	30-50	1.72556
Loblolly Pine	50-70	1.81986
Loblolly Pine-Hardwood	10-20	1.78622
Loblolly Pine-Hardwood	30-50	1.76692
Loblolly Pine-Hardwood	50-70	1.78235
Sweetbay-Swamp Tupelo-Red Maple	20-30	1.60378
Sweetbay-Swamp Tupelo-Red Maple	50-70	1.70245
Bottomland Hardwood-Yellow Pine	30-50	1.66307
Bottomland Hardwood-Yellow Pine	50-70	1.76612
White Oak-Black Oak-Yellow Pine	30-50	0.67828
Sweetgum-Nuttall Oak-Willow Oak	50-70	1.81293
Table modified from Balbach et al. (1995).		

communities, when most in fact are more appropriately defined as different seral stages of the same general community. Additionally, the vertical height classes were combined into one layer. The plant communities were broadly defined and data strata were "pooled" simply to illustrate the application of real data, but doing so resulted in a relatively high degree of variability and a poor ability to discriminate communities. FHD values calculated annually can provide one metric of community structural change. Data and calculations required to estimate FHD values in addition to other vegetation attributes can be found in Cooperrider, Boyd, and Stuart (1986).

Density of structural items in the landscape is a significant influence on biodiversity. Consider the density of snags (dead standing trees) and their impact on influencing bird community composition. In addition to providing breeding areas to cavity-nesting birds, snags are also used as perching sites or foraging substrates by numerous other avian species (Davis 1983). Moreover, countless other vertebrate and invertebrate species use snags as a source of cover or food (e.g., termites, fungi). Based on LCTA belt data, Whitworth (1995) estimated a mean snag density of

1.28 snags per ha on Fort Sill, OK. This figure is believed to be within acceptable limits as suggested by Fager, Capp, and Sheppard (1984).

Figure 9 values represent the overall mean canopy cover values recorded for 100 points along each transect. All hits were considered, because using only the top-most hits would result in an even stronger bias toward woody species. Canopy cover was generally present and most often provided by woody or other perennial species. Overall, annual plant

species appeared to provide a relatively insignificant contribution to the canopy, at least on the core plots. An important consideration when interpreting this figure is that maintaining consistency between years with respect to the proportion of perennial, annual, and no canopy cover does not necessarily mean biological diversity is being maintained.

The great pine belt, longleaf in particular, has been described as a subclimax maintained by fire (Society of American Foresters 1980; Christensen 1981). Pine occupies many upland sites, with hardwood restricted largely to bottomland and more mesic sites. Fire suppression has been shown to decrease diversity and increase the probability that rare and indigenous species will be eliminated (Noss 1988). A gradual shift from a primarily coniferous canopy to deciduous canopy on upland sites, indicative of long-term fire suppression (although other ecological process could be involved), would simply not be evident in Figure 9. Thus, of greater relevance to biodiversity characterization in the southeast may be monitoring a compositional subcomponent of vertical cover: the contribution of coniferous vs. deciduous species. Overall, 60 percent of the vertical hits recorded on the core plots on Fort Benning, GA, were attributed to coniferous species. A more detailed breakdown (Figure 10) of this total indicates that broadleaf species form a greater proportion of the canopy in coniferous habitats (20 percent) than conifers do within deciduous habitats (10 percent). The apparent significance of this discrepancy is unclear, as it is not uncommon for a stand of conifers to be dissected by one or more narrow drainages or wetlands, with mesic areas clearly favoring the establishment

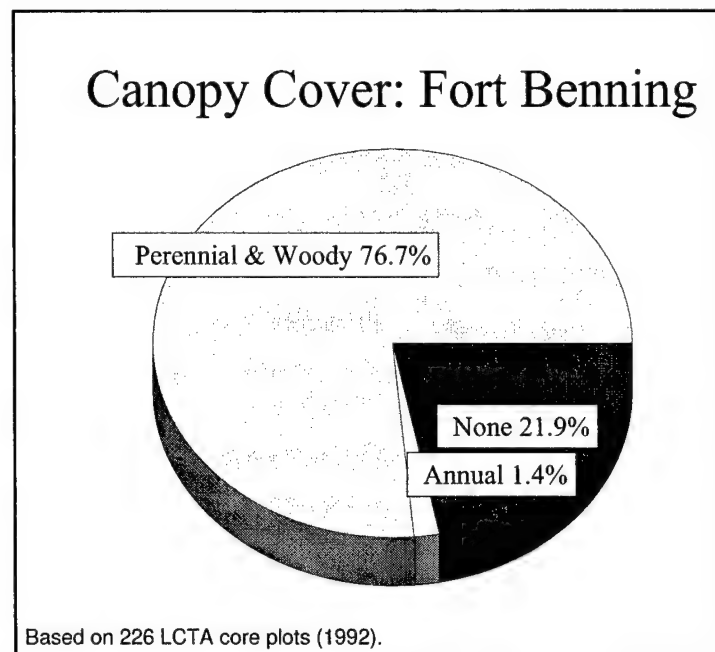
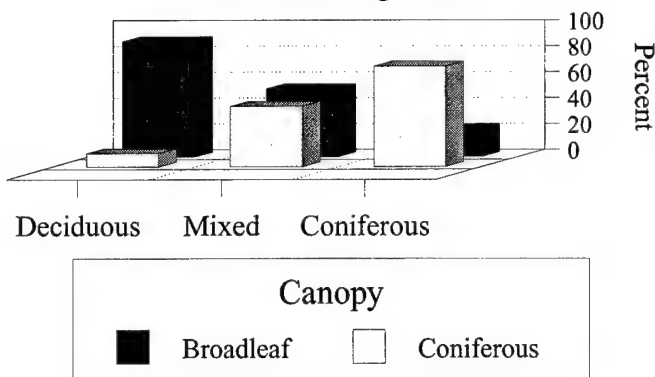


Figure 9. Percentages of canopy cover, when present, attributed to perennial and annual species.

Perennial Canopy Composition

Fort Benning, GA



Based on 1991 LCTA data (13,987 total vertical hits).

Figure 10. Percentage of perennial canopy cover attributed to coniferous and broadleaf species within deciduous (n=83 plots), coniferous (n=72), and mixed (n=18) plant communities.

and persistence of broadleaf species. A more relevant consideration of these percentages is whether they change significantly over time. Thus, the real usefulness of this 1-yr data in supporting this structural attribute of biodiversity will only become apparent after more years of monitoring.

Figure 11 values represent the overall mean ground cover values recorded for 100 transect points on each of the 226 core plots (a total

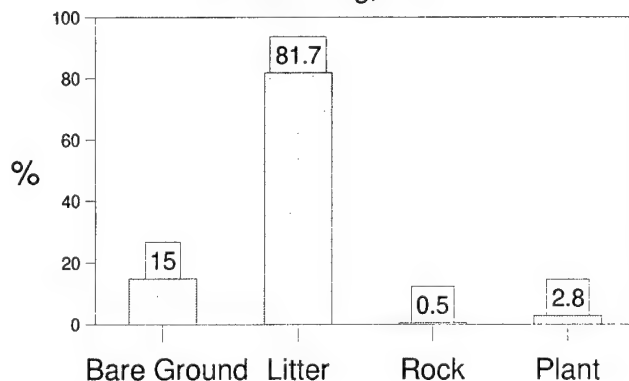
of 22,600 points). It further indicates that, on the core plots, litter was by far the most frequently encountered ground cover, bare ground was uncommon, and exposed rock was relatively rare. This interpretation of ground cover is consistent for a landscape dominated by a perennial canopy (Figures 9 and 10). Litter depth, also an important influence on diversity, is not a standard requirement at present and is taken only at the discretion of the LCTA field crew.

A limited number of wildlife community attributes can be summarized from current LCTA protocol. Male to female ratios can be tallied and are often useful in characterizing population demographics.

For birds, the number of singing males and male/female pairs can be summarized as a rough index of breeding activity at a site. However, it is important to remember that although signs of breeding activity are documented, standard LCTA data (as explained in Tazik et al. 1992b) do not provide evidence that breeding actually took place, that it took place on the plot, or that it was successful. Expanding data collection

Ground Cover Summary

Fort Benning, GA



Based on 226 LCTA core plots.

Figure 11. 1992 percent ground cover summary for Fort Benning.

to include nest searching and monitoring is possible and would provide quantitative verification of nesting activity inferred by audio (singing males) and visual (male/female pair) data currently collected on the plots.

LCTA's remote-sensed data represent a *potential* wealth of information relative to biodiversity assessment, but issues regarding image accuracy and resolution (scale) hamper its widespread acceptance and use (Senseman et al. 1996). For a geographic information system (GIS) to be an effective management tool, the image on the screen must accurately portray communities as they occur in the field. Reflectance values derived from satellite imagery are the basis by which LCTA habitats or communities are delineated and core plots allocated. These values are often stored as map "layers" in a GIS such as GRASS (USACERL 1993). The applicability of LCTA map layers to characterize and monitor biodiversity structure is probably best determined by the amount of resources available to land managers for ground-truthing each satellite image, resources that often are unavailable. Assuming that each of the reflectance value groupings does, in fact, correspond to ecologically meaningful communities, then characterizing structural attributes of biodiversity at the landscape level may be an appropriate application of LCTA resources.

Specifically, structural attributes of interest include community heterogeneity, connectivity, degree of patchiness, patch size, configuration, juxtaposition, and perimeter-to-area ratio (Table 1). Due partly to publicity surrounding the loss of old-growth forest in the Pacific Northwest and rain forests in Central America, the size and arrangement of patches or "communities" has received a good deal of attention in the literature, particularly with respect to bird abundance and distribution (e.g., MacClintock, Whitcomb, and Whitcomb 1977; Blake 1983; Blake and Karr 1984; Harris 1988). As contributors in the development of island biogeography theory, MacArthur and Wilson (1967) and Pickett and Thompson (1978) provide specific examples and more thorough discussions on the unquestionable importance of landscape attributes in influencing biological diversity. Balbach et al. (1995) repeatedly used LCTA-generated map layers and data to address these issues, calculating expected increases in total open (nonforested) area, number and mean size of forest fragments or "islands," and fragment edge-interior ratios as a means to objectively differentiate each of six proposed mission change alternatives for one southeastern Army installation.

Descriptive Measures: The Characterization of Function

Monitoring functional attributes of biodiversity with current LCTA protocols is clearly limited. Ecological processes such as nutrient cycling, energy flow, erosion,

productivity (primary and reproductive), survivorship, dispersal, recruitment, competition, and gene flow are unquestionably important but simply beyond a generalized land characterization program. However, standard core plot data can provide at least a cursory treatment of several functional indicator variables such as military land disturbance and land-use trends, soil erosion, and wildlife population fluctuations.

Figure 12 values represent the overall mean ground disturbance values recorded for 100 points along each of the 226 core plots (a total of 22,600 points). The data indicate a relatively low percentage of training-related disturbance on the core plots themselves. To conclude from this figure that the training lands are being underutilized cannot be supported. The lack of extrapolation "power" of LCTA data to support functional attributes of biodiversity can be attributed to an economic-driven bias in the core plot allocation process. Many of the more environmentally damaging training events are restricted to specific areas on an installation primarily due to safety requirements or proximity to impact areas. Topography and vegetation (concealment cover) are important considerations as well, but likely given secondary priority. Thus, because military training area is not a third stratification factor in the allocation process, a bias is associated with this application. Nevertheless, it is important to monitor disturbance in some form, for it clearly influences diversity by creating primary successional habitat and artificially maintains others in early successional stages, thereby preventing the development of the more biologically rich climax communities.

To the military land manager, soil loss due to erosion can result not only in unacceptable sediment loads in adjacent aquatic systems (short-term) but has more direct and predictable effects on terrestrial communities (longer-term). These effects

include: (1) increasing the amount of open area, thereby encouraging weed species invasion (Bultsma and Lynn 1985; Trumbull et al. 1994), (2) increasing community recovery time (Thurow, Warren, and Carlson 1993), and (3) simultaneously decreasing native floral and faunal diversity (Severinghaus, Riggins, and Goran 1979; Severinghaus and Goran 1981; Krzysik 1994). Considering that soil

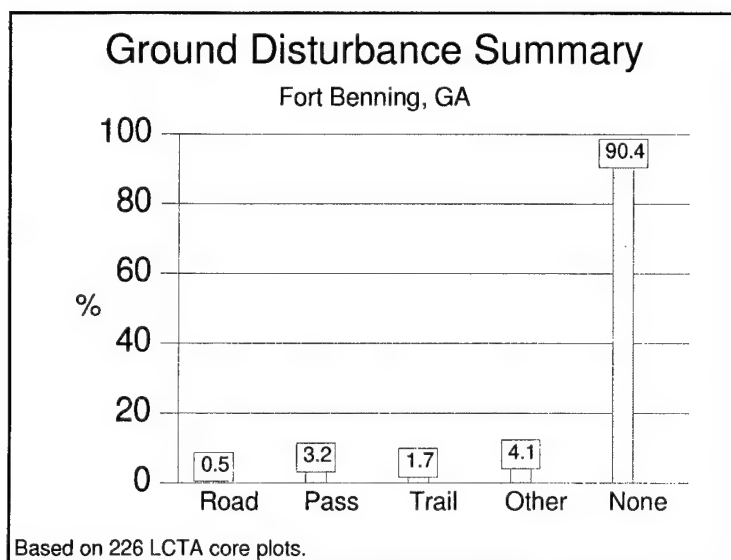


Figure 12. 1992 military ground disturbance summary.

microorganisms perform many significant functions in ecosystem development and maintenance (Bernard 1992) and are, by themselves, a tremendous source of biological diversity (Olembo 1991; Odum 1994), the ecological ramifications of excessive soil loss become more evident. Approximately 30 percent of the core plots on Fort Benning exhibited signs of recent water erosion such as sheet/rill, active gully, and debris dams (Figure 13). In contrast, 5 percent of the core plots exhibited signs of wind erosion—drifting, scouring, and the presence of pedestal plants. LCTA aerial and land ground cover data can fine tune the universal soil loss equation (USLE), widely accepted as the standard in estimating soil erosion potential, for each ecological response unit (Shaw and Diersing 1989; Warren et al 1989; Warren and Bagley 1992). Once erosion potential is identified, allowable levels of tracked vehicle use can be estimated and adjusted based on changes in ground cover and botanical species composition (Diersing et al. 1988; Shaw and Diersing 1989).

It is unknown whether the percentage of plots exhibiting noticeable signs of erosion is an accurate portrayal of conditions typical for the “normal” range of conditions expected for the communities on the installation. However, the lack of military disturbance on the plots (Figure 12) is consistent with the supposition that they could. Remember also that current LCTA protocol documents evidence of past erosion but does not quantify how fast soil is being lost (i.e., rates), where the soil is being redeposited, or the effects on the remaining upper layers of the soil profile. Again, the usefulness of LCTA data to characterize soil resources across landscapes should be exercised with caution, a constraint arrived at early in the plot allocation process. Specifically, military training was not a stratification factor in the core plot allocation process and, as a result, it is virtually guaranteed that LCTA core plots do not adequately portray the full range of training sites, training activities, and geomorphological variables such as slope and slope length across an installation—variables of unquestionable importance with regard to soil erosion potential in the southeastern United States (Balbach et al. 1995). On the other hand, LCTA data give at least a cursory measure of

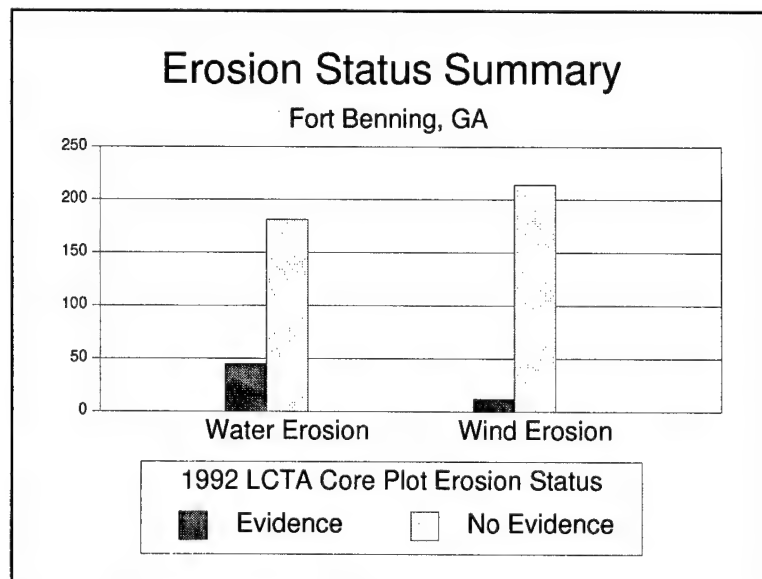


Figure 13. Total number of LCTA core plots (n=226) on Fort Benning exhibiting evidence of wind and water erosion.

erosion status on the core plots—perhaps an acceptable tradeoff considering the breadth of the program and strong user-identified emphasis on cost containment (Schreiber et al. unpublished).

Table 11 values were summarized from the LCTA individual plot map forms and not from line transect data. That is, values are based on one general observation of the immediate plot area and not on an averaged assessment of land-use measurements taken on each of the 100 points comprising the line transect. This table suggests the majority (59 percent) of core plots on Fort Benning were recently impacted by some type of military activity, foot traffic being the most prevalent type. Commercial forestry was the most prevalent nonmilitary land use, with over 50 percent of the plots exhibiting recent evidence of row cropping, selective harvesting, etc.

Noss (1990) suggests wildlife population fluctuations as a potential indicator in supporting biodiversity characterization at the population level (Table 1). In contrast to vascular plants, determination of presence, association with habitat, and population size for wildlife is complicated by their ability to avoid detection by researchers and their great mobility (see also Price et al. 1995). Further confounding our ability to characterize wildlife is the tendency of animal populations to exhibit dramatic between-year fluctuations with no corresponding change in habitat

Table 11. 1992 land use summary for Fort Benning, GA.

Land Use Type		# Plots Showing Evidence of Use	% Plots Showing Evidence of Use
Military	<i>Bivouac Site</i>	3	1.3
	<i>Excavation Area</i>	22	9.7
	<i>Foot Traffic</i>	114	50.2
	<i>Wheeled Vehicle</i>	18	7.9
	<i>Tracked Vehicle</i>	15	6.6
	<i>Other^a</i>	19	8.4
	<i>None</i>	94	41.4
Nonmilitary	<i>Forestry</i>	122	53.7
	<i>Row Crop</i>	2	0.9
	<i>Other^b</i>	3	1.3
	<i>None</i>	102	44.9
Note: Based on 227 individual core plot summary forms.			
^a Includes landing and drop zones, live firing ranges, ammunition points, etc.			
^b Includes TES colony sites and other protected areas.			

apparent, making the requirement of long-term (5+ yr) data critical in differentiating trend from natural variability. Unfortunately, long-term wildlife data on installations in the southeastern region were not available at the time this report was written; therefore, no specific examples are provided. However, a recent evaluation by Warner, Brawn, and Heske (1996) on Army lands in the north central United States provides some guidance and insight into the ability of standard LCTA methods to detect change (trend) in small mammal and bird populations. The following abbreviated discussion on small mammals and birds consists largely of selected excerpts (paraphrased) from Warner, Brawn, and Heske's (1996) evaluation, with particular attention to conclusions and recommendations. It is important to note that all analyses were conducted at the landscape or installation scale (i.e., data were pooled) and that variability within and between habitats, although of great interest, was not assessed because of small sample sizes.

Small mammals: LCTA indices of abundance can be plotted annually based on mean number captured per plot and by total captures per installation. Using total captures as the index of abundance should be considered only if the survey efforts were identical, that is, the same number of plots were surveyed in both years. Otherwise, rarefaction procedures should be used to estimate species richness when comparing surveys that differ in sampling effort. The minimum number of plots required for a reasonably good Alpha diversity (H') estimate is 20; however, a sample size of 50 to 60 plots per survey is recommended to gain the most benefit in terms of narrow confidence intervals (CI), greater statistical power from sampling effort, and attain a reasonable probability that most species present will be detected. Resampling procedures should be used to estimate CIs around indices of abundance. A 95 percent CI, for example, indicates the range of values that includes the true mean with a 95 percent probability.

Statistical power is the probability of detecting a significant difference (often reported at the 0.05 alpha level) when in fact there is one (Cohen 1988). Two-mean t-tests and repeated measures of analysis of variance (rmANOVA) were applied to LCTA data and statistical powers measured. Effect size is the parameter of comparison and is simply a measure of the degree of difference between means and is not expressed in the original units. For two-mean t-tests, Cohen (1988) defines a "small" effect for a normal distribution as 0.2, a "medium" effect as 0.5, and a "large" effect as 0.8. These small, medium, and large effects correspond roughly to 20, 50, and 80 percent differences between two sample means. For the rmANOVA, effect size is based on degrees of freedom, sample size, and the F-ratio, whereas 0.1 indicates a small effect: 0.25, a medium effect; 0.4, a large effect. In general and for both statistical tests, power analyses indicate that large and medium effect sizes are adequately detected by statistical tests from current protocol. Small effect sizes, however, cannot be readily distinguished from sampling error under current protocols. Probably of

greater importance is the finding that attaining adequate statistical power at the individual species level was restricted to a relatively few, highly abundant species. They caution that, for the short-term, even significant differences will boil down to subjective interpretations, pointing out that lack of power to detect small effects may be an unfortunate but acceptable consequence of logistical and financial constraints.

Birds: Similar to small mammals, LCTA indices of abundance can be plotted annually based on mean number captured per plot and by total observations (captures) per installation. Again, two-mean t-tests and rmANOVA were applied to LCTA data and statistical powers of the tests measured. In general, the ability of current protocols to detect medium and large changes appears adequate if all 60 wildlife plots are surveyed. The power to detect small effects between years was weak (0.24). The number of plots needed to detect a small effect with a probability of 0.8 or more is estimated at 120 plots per year. Current sampling efforts appear adequate for estimating species richness and obtaining reasonably precise estimates of abundance. In years where survey efforts differ appreciably, rarefaction analyses (Cohen 1988) are suggested.

Interpretation of Biodiversity Summaries

General Comments

With respect to diversity, is the data good, bad, or what? Arguably, being asked to answer a complex ecological question with a simple answer may be the single most prevalent reason a gap exists historically between military trainers and natural resource professionals. Placing the data presented in this report in the proper context is best accomplished by the installation natural resources personnel. These individuals have the necessary institutional knowledge of their installation's land-use history, current forestry practices, core plot allocations, ecological communities, climatic patterns, seasonal variability, and the location and *purpose* of special-use plots to make biologically meaningful interpretations. Moreover, the installation personnel are the most qualified in assessing how accurately the standard plot allocation process actually reflects the range of conditions on the installation.

The use of standardized methods is a cornerstone of the LCTA program. Standardization is a means to minimize the likelihood of confounding true ecological differences with that of survey methodologies. Summaries presented in this report show how a series of LCTA data and automated, but individual, analyses can be integrated or "packaged" to more effectively support the characterization of an installation's biological diversity. Comments, issues of concern, and desirable

analyses with regard to biological diversity are discussed in Balbach et al. (1995) and provide a more "grass-roots" perspective into what public groups and regulatory agencies' believe should be addressed by installation land managers in the southeast. Brief discussions on four of the more recurrent concerns/issues follow.

1. *Are the ecological communities (species assemblages) currently present on the installation **representative** of the ecosystem / landscape that would be expected in the absence of commercial / military development (presettlement conditions)? Secondly, are the communities functional—do they interact properly?*

An example of the functional consideration is provided by a hypothetical ½ ha plot of "native prairie" occurring in a city park in the Great Plains region. Natural processes such as fire and grazing by large ungulates are absent on the plot, and plant species composition and abundance are controlled by humans. Thus, while the plant species themselves might represent what would have been expected on the site 200 yr ago, the plot is more accurately described as a "grassland" (an area covered by grass) rather than a functioning prairie.

When assessing whether communities are "representative" or not, the integration of several approaches often is required. To adequately describe an installation's natural communities and form the basis by which to "consider" environmental impacts from Army activities as mandated by NEPA (1969), three recommended approaches are to:

- Document any "pristine" habitat on or in relatively close proximity to the installation to use as a basis for comparison. The level of detail in data collection in the pristine vs nonpristine, trained on, or otherwise military-modified habitats should be comparable. The use of LCTA plots within pristine habitats is one potential source of information.
- Conduct a thorough literature search and review, paying particular attention to (any) reliable historical accounts by early naturalists.
- Consult local experts such as the Nature Conservancy, Natural Heritage Program, and natural history professionals working for state agencies. Many groups have prioritized conservation lists that, as objectively as possible, rank all species based on a combination of criterion such as a species area or home range requirements, endemism, reproductive potential, tolerance to habitat fragmentation, listing as threatened or endangered, number of obligate and facultative associates, and in general its perceived importance or contribution to maintaining diversity at the state/region/continental levels.

2. What are the known and potential impacts of past, present, and future military activities (and other land uses) on community composition, structure, and function?

Relatively short-term, cause and effect issues such as these are difficult to answer conclusively without controlled, pre-impact studies (Price et al. 1995). Even more difficult is the issue of addressing cumulative effects on biodiversity. Regardless, the use of LCTA core and special-use plots on and off the installation can help address these issues given sufficient time for planning and adequate resources. However, past impacts often must be inferred largely from historical accounts and data collected from other regions or areas with dissimilar land-use histories.

3. What role have introduced species played in influencing community composition, structure, and function?

Past land rehabilitation efforts sometimes can inadvertently promote the use of certain exotic species either (1) because of superior trafficability, ability to decrease soil loss while adding nitrogen to the soil, and resistance to fire or, more simply, (2) that native species may not have been readily available as seed (i.e., cost prohibitive). Other exotic species such as kudzu and purple loosestrife have become established by contamination of native seeds, civilians driving/walking onto installation lands, or "natural" encroachment from previously infected adjacent lands. Unfortunately, the predisposition of some exotics to disturb conditions found on many active training lands, coupled with a high competitive ability, can have serious negative impacts on biodiversity. Again, given sufficient time for planning and adequate resources, LCTA data can represent a potential source of information. However, historical accounts and direct comparisons with pristine communities must be relied upon to provide the best guess for assessing past influences of introduced species on diversity.

4. What pieces of the biodiversity puzzle are LCTA data capable of supporting at present (see Table 1) or, conversely, what pieces are not supported at present?

Standard LCTA data by itself will provide the installation land manager a limited amount of biodiversity information. Gaps and deficiencies in LCTA coverage exist and should be recognized when assessing biodiversity on Army lands. Although potential "add-ons" to methodology are being considered, the applicability of current LCTA survey or plot inventory data are limited to addressing the components of biodiversity listed in Table 1: composition, structure, and function.

Composition: The LCTA program was intentionally biased toward the more common terrestrial vascular plants and vertebrate animal species, given very real

limitations of time and money. Even with this bias towards a few broad "indicator" taxa, many species within these terrestrial groups are not adequately surveyed with existing methodologies. Some of these include large mammalian herbivores (deer), nocturnal birds (owls) and mammals (bats), aquatic and semi-aquatic birds (waterfowl, shorebirds), mammals (muskrat), subterranean small mammals (moles, pocket gophers), diurnal raptors (red-shouldered hawk), and terrestrial predatory mammals (red fox, mink). More obvious voids in species diversity information not presently collected on LCTA plots include, but are not limited to, the following large and very diverse groups:

- viruses
- bacteria
- algae
- mosses
- parasitic organisms
- protozoans
- insects
- arachnids
- crustaceans
- fishes
- annelids
- mollusks.

These large taxonomic gaps are formidable constraints but common in inventory and monitoring studies. Burley (1988) writes "identifying elements of biological diversity and monitoring their changes through time is a daunting task. Biologists have long recognized that the full array of biological diversity will never be known completely" Although an estimated 80 percent of the earth's biodiversity likely occurs in the tropics (Raven and Wilson 1992), the lack of taxonomic knowledge is problematic in North America as well. Kosztarab and Schaefer (1990), for example, estimate that only about one-half of the insect species occurring in the United States are known. A clear danger exists in focusing attention on a relatively few, high profile groups such as keystone species, indicator species, and TES. Odum (1994) regards microbial diversity, or as he terms it "invisible diversity," as potentially the most important aspect of Alpha diversity. He correctly points out the critical role these soil and litter microorganisms play in nutrient cycling, a process essential in the survival of the more "visible" species. Hendrix (1996) explores earthworms as a bridge between functional and taxonomic biodiversity studies in the southern United States. Finally, Stewart (1991) and Olembo (1991) discuss the extreme adaptability and genetic diversity of microorganisms and invertebrates. In summary, fiscal constraints effectively guarantee substantial gaps in coverage will exist in the LCTA program, and it is essential for the installation to review and utilize data from other internal or external sources to reduce the number of gaps in coverage.

Structure: The applicability of LCTA products to document heterogeneity (patchiness), juxtaposition, and perimeter-area ratios (Table 1) relate back to the

plot allocation process. The accuracy of each map layer is influenced by systems-related limitations such as the resolution of imagery or soils data and computer hardware capabilities. Human biases and error contribute to overall accuracy as well. Moreover, daily and seasonal variability in biotic and abiotic conditions such as cloud cover, season of the year, humidity, soil moisture, recent burn activity, slope, aspect, etc., can result in some communities (vegetation/soil combinations or "polygons") being grouped together and others split apart. Ground-truthing polygons combined with an adequate number of plots per polygon are essential and greatly expand the usefulness of the LCTA program to quantify the indicator variables.

Function: Some researchers (e.g., Angermeier and Karr 1994) consider many processes and rates identified by Noss (1990; Table 1) as attributes of biological integrity and not biological diversity. Whether processes and rates are measures of biodiversity or attributes of integrity is debatable. What is clear is that quantifying most processes and rates beyond simple population trends is beyond the scope of a general monitoring program such as the LCTA program.

Quantitative Diversity Indices

Traditional diversity indices (e.g., Shannon's), like all other indices, have limitations that need to be acknowledged when interpreting them. This section could also have been entitled "What a Diversity Index Will Not Tell You" or "Why Not To Rely on a Single Diversity Index as the Sole Basis From Which To Assess Biodiversity." The following general statements and issues are some of the more recurrent concerns expressed throughout the biodiversity literature, and can help to place LCTA data summaries in their proper context.

- Which diversity index to use is determined by the question being asked. Using an Alpha diversity index to compare the diversity of two habitats or two installations can result in comparable, or even identical, values when, in fact, they might represent very dissimilar ecological communities (little overlap) with respect to species composition and relative abundance. If documenting habitat uniqueness is the primary consideration rather than simple species richness/abundance issues, a Beta diversity analysis clearly would be more appropriate.
- Although heterogeneity-based diversity indices (species richness plus equitability) are frequently used, Peet (1974) asserts their proper calculation requires the number of species in the community be known, an accomplishment rarely achieved in ecological studies.

- Habitats and landscapes (installations) may have relatively high richness values yet not be highly representative, nor does this necessarily equate to a high habitat quality. A hypothetical example of the former would be a simple wiregrass community subsequently tracked by wheeled vehicles. Disturbance species, some of which are exotics, become widely established, resulting in a community showing an increase in richness but clearly less representative.
- Direct comparisons of two different Alpha diversity values should not be attempted because different indices emphasize different subcomponents (richness vs. evenness).
- Communities can have a low diversity and still be unique or highly representative. Generally, species diversity increases when moving from the northern latitudes to the southern latitudes and when traveling from high elevations to lower elevations (Odum 1971; Savage 1995). Caution should be exercised if comparing biodiversity between installations along one of these natural environmental gradients.

5 Summary

Army Regulation 200-3 (1995) requires commanders and land managers to consider the impacts of Army activities on biological diversity (biodiversity). Biodiversity has historically been described in terms of species richness, but is now recognized as being composed of highly interactive biotic and abiotic elements that occur at multiple spatial and temporal scales. In a simplistic sense, characterizing biodiversity deals with describing uniqueness—unique species assemblages, unique processes, unique structures, etc. This report briefly reviewed the concept of biodiversity and described the degree to which standard LCTA data can be applied towards its characterization. LCTA data summaries in this report were produced from data provided by Camp Shelby (MS), Fort Benning and Fort Stewart (GA), and will provide installation land managers in the southeastern United States more options in addressing biodiversity issues identified by Army regulations, federal and state government agencies, and the public.

Characterizing biodiversity on an installation, in a sense, means describing biological uniqueness. Describing uniqueness does not necessarily require the large-scale collection of new data sets. Rather, it requires the “repackaging” or rescaling of the same data set to view diversity as the multidimensional entity that it is. Possibly more important, repackaging can improve the communication link between the military training staff and natural resource staff. Biological data are of little value to a company commander unless they are in an understandable format. By adjusting the scale and/or changing the biological attribute being considered, the trainers, soldiers, and other nonbiologists will more likely be aware of and understand the ecological basis by which one area differs from another.

Three general attributes of biodiversity advocated by Noss (1990) are composition, structure, and function, all of which occur at the genetic, population, community, and landscape spatial scales. The contribution LCTA data make toward characterizing these three attributes across multiple scales is not complete nor uniform. LCTA data collected under current methodology clearly are most applicable at characterizing compositional, and to a lesser extent, structural attributes. Functional attributes such as land use, erosion status, and simple population trends can be supported to a limited degree. However, nutrient cycling,

population turnover, productivity, etc., while important to ecosystem integrity, are beyond the scope of a general land monitoring program such as LCTA.

The LCTA program was not developed specifically as a comprehensive program to characterize, assess, and monitor biodiversity *per se*. The biota of an installation is a composite of many, highly diverse groups such as vascular plants, insects, fungi, algae, protozoa, fish, mammals, reptiles, amphibians, crustaceans, worms, and bacteria. Given current and projected limitations of time and money, current methodology was focused on a few indicator taxa, intentionally being biased towards the more common terrestrial vascular plants and smaller vertebrate animal species. Even with this small number of indicator groups, it was cost-prohibitive to develop survey methodologies applicable to all species within each group. As such, individual species and species assemblages identified and diversity indices calculated based on current LCTA methodology will be a reflection of a *subset* of the terrestrial vascular plant and vertebrate animal elements within each plot, community, or landscape. Persons responsible for analyzing and interpreting LCTA data must keep this fact in mind. Moreover, land managers are strongly encouraged to seek additional data sources to address known deficiencies or gaps in coverage.

The installation LCTA floral checklist represents a cooperative effort between the floristic inventory and the plot inventory/survey. Floristic inventories are 1 to 3 yr efforts, while plot monitoring is conducted once annually for an indefinite period. Ideally, completed floristic inventories document 100 percent of the species occurring on an installation with the LCTA plots picking up a subset of that total. The degree to which the plot-based subset represents the total depends on the *number* and *distribution* of plots across the installation. Data analyzed to date suggest that, at least for three Army installations in the southeastern United States, floristic inventories are 76 to 86 percent complete and that the LCTA plots by themselves are "picking up" or monitoring approximately 40 to 50 percent of the known species for the installation. The deficit between the total species inventory and number of species being monitored on the core plots may be an acceptable compromise in light of economic and logistical constraints but can be alleviated somewhat by the judicious use of special-use plots or additional core plots.

Simple species checklists are an essential yet often under-appreciated first step in biodiversity assessments. Analytical diversity indices measuring within (Alpha) and between (Beta) habitat diversity form a second tier of analysis. Several examples of the use of these indices with LCTA data were provided. However, checklists and statistical indices by themselves have limited value. Rather, it is the life history attributes associated with each species that can be gleaned into more informative summaries for land management planning and NEPA documentation purposes. In

the guild concept, species are grouped based on how they use a particular environmental resource, thus allowing a more descriptive characterization of diversity than the traditional statistical indices. Moreover, the guild concept provides the land manager a means to link species to specific habitat variables rather than to entire habitats. Plant life history attributes considered in this report include plant growth form, origin, and life span. Avian species attributes considered include neotropical migrant status, foraging location, primary diet, and general nest location.

GIS data associated with the LCTA program represent a *potential* wealth of information relative to biodiversity assessment, but issues surrounding image accuracy and resolution (scale) continue to hamper its widespread acceptance and use. For GIS to be an effective management tool, the image on the screen must accurately portray communities as they occur in the field. The applicability of LCTA-GIS map layers to characterize and monitor biodiversity structure is probably best determined by the amount of resources available to a land manager for ground-truthing each satellite image; resources that seem to be steadily dwindling each year. Assuming that each of the reflectance value groupings do, in fact, correspond to ecologically meaningful communities, then characterizing structural attributes of biodiversity at the landscape level may be an appropriate application of LCTA resources.

Arguably, maintaining genetic diversity may be the single most important factor in permitting plant and animal populations to persist and adapt. Genetic analyses of specimens collected through the LCTA program were not identified as a priority (Tazik et al. 1992b), although the potential for LCTA data to contribute a minimal level of information regarding genetic diversity appears favorable. Samples of plants and animals collected with the LCTA program could be submitted for genetic analyses to assess within and between population genotypic diversity, variability, and the delineation of metapopulations. However, the cost effectiveness of adding this requirement has not been thoroughly investigated.

The appropriate scale at which LCTA data can be summarized is best determined by installation personnel, with the standard core plot allocation procedure typically being used to generate individual plot, broad community, and landscape-level summaries. Scale limitations are partly a result of the process by which LCTA plant communities are defined. Communities are initially defined based on vegetation reflectance values derived from unsupervised satellite imagery and general soil maps. Additional core plots based on known species population distributions or comprehensive vegetation community maps in concert with the judicious use of special-use plots could increase the applicability of LCTA data at the community and population scales.

Other recommendations to installations in the southeastern United States fielding LCTA are to:

- Conduct a comprehensive literature review to establish what historical communities and presettlement conditions existed on the installation lands before and after the arrival of the military. The quality and quantity of natural history accounts written by early naturalists varies widely, and although few provided comprehensive quantitative accounts, they can be useful in assessing what the "natural" communities should resemble and how far the installation has deviated from this condition. What constitutes presettlement conditions on an installation might come down to a "best guess" by local experts from the Nature Conservancy or the state Natural Heritage Program. Their input should be obtained as their "best guess" in any case and will undoubtedly be perceived by public groups scrutinizing Army activities as lending credibility to the Army's "best guess."
- Consult with the state Natural Heritage Program for a list of species recorded in or adjacent to the counties affected by the installation. Natural Heritage Programs also disseminate information regarding the importance of each species to state, regional, and global biodiversity in addition to their state and Federal listing status. These types of information are consistent with an ecosystem-based management approach, can be updated annually, and are easily integrated into LCTA data summaries.
- During the initial plot inventory and on subsequent monitoring years, records of fire occurrence, intensity, and whether the burn was prescribed or accidental would help monitor this significant component of southeastern ecosystem function (and its influence on composition and structure) and is important when interpreting plot data. Intensity, for example, could be expressed in terms of what percent of the 100 line-transect points had been burned. If the cause of the fire is not readily apparent to the technician in the field, the installation range control or fire department personnel should be able to assist in the determination.
- Allocating additional plots based on a supervised, ground-truthed satellite image would increase the applicability of LCTA data in characterizing biodiversity at the community level. Proportional allocation of additional plots based on ecologically distinct and ground-truthed plant communities could improve the usefulness of LCTA data to characterize biodiversity at the community level and has the added benefit of increasing the data pool for installation-wide summaries.

- Maintain strict quality control both in survey protocol and plot survey timing. Modifications in survey and inventory methodology to answer a specific problem or "customization" of LCTA data to a specific ecoregion can often be accommodated while still allowing for data comparisons with previously collected data. However, between-year comparisons are difficult at best if protocol and survey timing changes from year to year.
- Apparently, many species identified in the floral inventory are not being "picked up" on the core plots. If monitoring a greater proportion of the less common (total) species on an installation is desired, special-use plots should be allocated to the appropriate habitats.
- Consider augmentations to current data collection efforts that will improve the applicability of LCTA data in characterizing and monitoring keystone, critical link, and endemic species. As an example, consider an endemic, keystone species: the gopher tortoise. Burrow-count transects are probably the most widely used technique for estimating gopher tortoise populations, with Burke and Cox (1988) reporting transect dimensions of 100 to 250 m long by 7 to 10 m wide. This technique is relatively quick, requires no additional equipment than that specified in Tazik et al. (1992b), and is amenable to the scale of the LCTA plot as presently defined. Camp Shelby has established and monitored a number of LCTA plots in gopher tortoise habitat since 1991 (Balbach et al. 1995).
- Consider other potential modifications or enhancements to current data collection efforts that will improve the applicability of LCTA data to characterize biodiversity on Army lands such as: (1) expanding the use of special-use plots (controls) to discern military effects from inherent variability, (2) increasing the use of special-use plots to expand monitoring coverage in unique, small (in terms of area), or otherwise under-represented communities omitted from the initial plot allocation process, (3) conducting seasonal LCTA surveys to address temporal influences on biodiversity, (4) expanding wildlife monitoring to include invertebrate species, (5) expanding bird surveys to include nest searching and monitoring to provide quantitative verification of breeding activity inferred by the audio (singing males), and visual (male/female pair) information currently collected, (6) incorporating surveys for subterranean biota, (7) incorporating surveys for aquatic vertebrate and invertebrate faunal species, and (8) incorporating genetic analyses of selected flora/fauna species collected during survey periods to document genetic diversity with the ultimate goal of delineating plant and animal metapopulations across the landscape.

Glossary

ABIOTIC: Nonliving; as applied to the components or processes of ecosystems (Allaby 1992).

ALPHA DIVERSITY: The number of species in a single habitat or community (Whittaker 1972; Spellerberg 1993).

BETA DIVERSITY: The change in species composition along an environmental gradient or series of habitats (Noss 1983), often expressed in terms of a similarity index between habitats or communities (Huston 1994). A high Beta diversity value (β) would indicate a low degree of similarity between communities along a gradient, while a low β would indicate a high degree of similarity.

BIODIVERSITY: The sum of all native, representative biotic and abiotic constituents, and assemblages, which exist at, but are not restricted to, genetic, population, ecosystem/community, and landscape levels, with each level containing highly interdependent and dynamic compositional, structural, and functional attributes.

BIOTIC: Living; as applied to the components or processes of ecosystems (Allaby 1992).

BIOLOGICAL DIVERSITY: See biodiversity.

BIOLOGICAL INTEGRITY: Refers to an ecosystem's wholeness, including presence of appropriate elements and occurrence of all processes at appropriate rates characteristic of an area. In contrast to diversity, refers to conditions present or expected under little or no influence from human actions (Angermeier and Karr 1994).

BRAC: Base Realignment and Closure; a process managed by the Army's Base Realignment and Closure Office (BRACO) in the office of the Assistant Chief of Staff for Installation Management (ACS(IM)).

COMMUNITY: An assemblage of all populations living in a defined area.

ECOLOGICAL SUCCESSION: The nonseasonal, directional, and continuous pattern of colonization and extinction on a site by species populations (Begon, Harper, and Townsend 1990).

ECOSYSTEM: The biotic and abiotic components of an environment that interact to produce a flow and cycling of energy (Landres 1992).

ENDEMIC: Species whose distribution is restricted to a specific continent, region, or area.

EXOTIC SPECIES: Those species whose occurrence on a continent, habitat, or region is the result of human transport (introduction) and not a natural dispersal mechanism (e.g., emigration or migration). "Naturalized" species such as the ring-necked pheasant are included in this category. Exotic species are also referred to as "introduced" species.

GAMMA DIVERSITY: The total species diversity of a large geographic region (Whittaker 1972).

GUILD: A group of species that use a similar resource (Landres 1986); A group of species that exploits the same class of environmental resources in a similar way (Root 1967).

KEYSTONE SPECIES: Species that, by virtue of their persistent presence in an area, can markedly influence ecosystem composition, structure, and function; a functional group without redundancy (Chapin, Schulze, and Moone 1992).

LANDSCAPE: A mosaic of heterogeneous land forms, community types, and land uses (Urban, O'Neill, and Shugart 1987) over a broad area. The physical dimensions of this area could be comparable to a national park or forest, an entire Army installation, or a physiographic region.

METAPOPOPULATION: A collection of interacting populations, linked through dispersal (Ruggiero, Hayward, and Squires 1994).

NATIVE SPECIES: Naturally occurring in an area (see Exotic Species).

NICHE: The environmental limits within which individuals of a species can survive, grow, and reproduce (Begon, Harper, and Townsend 1990).

POPULATION: A collective group of all individuals of the same species occupying a defined area, able to interbreed, and exhibiting characteristics and properties unique to the group and not expressed by individuals within the group (e.g., dispersal rate, sex ratios, mortality and birth rates).

SERAL STAGE: One of a series of relatively distinct yet overlapping successional communities ranging from primary to climax; seral stages have been variously referred to in more simplistic terms as being an "early" or "late" successional stage.

SPECIES: A group of organisms capable of interbreeding that are reproductively isolated from other such groups.

TROPHIC LEVEL: Position in the food chain assessed by the number of energy-transfer steps required to reach that level (Begon, Harper, and Townsend 1990).

TROPHODIVERSITY: Ecological diversity of a community based on the food-web theory; the diversity of trophospecies in a community (Yodzis 1993) (see trophospecies).

TROPHOSPECIES: The set of all species that share some particular set of predators and prey (see trophodiversity) (Yodzis 1993). In contrast to grouping species based on the "guild" concept, grouping species based on trophospecies traditionally classified as occurring in different "guilds" may be considered the same trophospecies.

References

- Allaby, M., *The Concise Oxford Dictionary of Botany* (Oxford University Press, 1992).
- Allard, D.L., *Community Characterization Abstract, Wet Longleaf Pine Flatwood*, The Nature Conservancy, Southeast Regional Office (Chapel Hill, NC, 1990).
- Anderson, A.B., P.J. Guertin, and D.L. Price, *Land Condition Trend Analysis Data: Power Analysis*, Technical Report (TR) 97/05 (U.S. Army Construction Engineering Research Laboratories [USACERL], October 1996).
- Angermeier, P.L., "Does Biodiversity Include Artificial Diversity?," *Conservation Biology*, vol 8 (1994), pp 600-602.
- Angermeier, P.L. and J.R. Karr, "Biological Integrity Versus Biological Diversity as Policy Directives," *BioScience*, vol 44 (1994), pp 690-687.
- Army Regulation 200-3, *Natural Resources--Land, Forest and Wildlife Management* (Headquarters, Department of the Army [HQDA], Washington, DC, February 1995).
- Auffenberg, W., "Gopher Tortoise," pp 33-35 in R.W. McDiarmid, ed., *Rare and Endangered Biota of Florida* (Florida Game and Freshwater Fish Commission and Univ. Presses, Gainesville, FL), *Amphibians and Reptiles*, vol 3 (1978).
- Austin, M.P., and C.R. Margules, "Assessing Representativeness," in M.B. Usher, ed. *Wildlife Conservation Evaluation* (Chapman and Hall, London, U.K., 1986), pp 45-67.
- Balbach, H.E., D.L. Price, W.R. Whitworth, M.K. Chawla, and E.R. Schreiber, *Military Training Use of National Forest Lands, Camp Shelby, Mississippi*, Special Report 95/10, vol 1 ADA295359, vol 2 ADA295358, vol 3 ADA295360 (USACERL, June 1995).
- Begon, M., J.L. Harper, and C.R. Townsend, *Ecology: Individuals, Populations, and Communities, Second Edition* (Blackwell Scientific Publications, 1990).
- Bernard, E.C., "Soil Nematode Biodiversity," *Biology and Fertility of Soils*, vol 14 (1992), pp 99-103.
- Biodiversity Task Force, *The Biodiversity of Missouri* (Conservation Commission of the State of Missouri, 1992).
- Blake, J.G., "Trophic Structure of Bird Communities in Forest Patches in East-Central Illinois," *Wilson Bulletin*, vol 95 (1983), pp 416-430.

- Blake, J.G., and J.R. Karr, "Species Composition of Bird Communities and the Conservation Benefit of Large Versus Small Forests," *Biological Conservation*, vol 30 (1984), pp 173-187.
- Boice, L.P., "The Department of Defense's Natural Resources Management Program: Integrating Stewardship and Mission Requirements," *The Environmental Professional*, vol 14 (1992), pp 84-87.
- Bogan, M.A., R.B. Finley Jr., and S.J. Petersburg, "The Importance of Biological Surveys in Managing Public Lands in the Western United States," pp 254-261 in R.C. Szaro, K.E. Severson, and D.R. Patton, technical eds., *Management of Amphibians, Reptiles, and Small Mammals in North America, Proceedings of the Symposium*, General TR RM-166 (USDA, Forest Service, Flagstaff, AZ, 1988).
- Bray, J.R., and J.T. Curtis, "An Ordination of the Upland Forest Communities of Southern Wisconsin," *Ecological Monographs*, vol 27 (1957), pp 325-349.
- Brillouin, L., *Science and Information Theory* (Academic Press, NY, 1956).
- Brower, J.E., J.H. Zar, and C. Von Ende, *Field and Laboratory Methods for General Ecology* (W.C. Brown Publishers, Dubuque, IA, 1990).
- Brown, J.H., and E.J. Heske, "Control of a Desert-Grassland Transition by a Keystone Rodent Guild," *Science*, vol 250 (1990), pp 1705-1707.
- Bultsma, P.A., and R.G. Lynn, "Survey for Spotted Knapweed in North Dakota," *North Dakota Farm Research*, vol 43 (1985), pp 19-22.
- Burke, R.L., and J. Cox, "Evaluation and Review of Field Techniques Used to Study and Manage Gopher Tortoises," pp 205-251 in R.C. Szaro, K.E. Severson, and D.R. Patton tech eds., *Management of Amphibians, Reptiles, and Small Mammals in North America, Proceedings of the Symposium*, USDA Forest Service General Technical Report RM-166 (Flagstaff, AZ, 1988).
- Burley, F.W., "Monitoring Biological Diversity for Setting Priorities in Conservation," pp 227-230 in E.O. Wilson and F.F. Peter, eds., *Biodiversity* (National Academy Press, Washington, DC, 1988).
- Chapin, F.S., E.D. Schulze, and H.A. Moone, "Biodiversity and Ecosystem Processes," *Trends in Ecological Evolution*, vol 7 (1992), pp 107-108.
- Christensen, N.L., "Fire Regimes in Southeastern Forests," *Proceedings: Fire Regimes and Ecosystem Properties Conference*, Technical Report WO-26 (USDA, Honolulu, HI, December 1981).
- Cohen, J., *Statistical Power Analysis for the Behavioral Sciences, 2nd Edition* (Lawrence Erlbaum Associates, Hillsdale, NJ, 1988).
- Cohn, J.P., "Defending the Environment," *ZooGoer* (May/June 1995), pp 13-22.

- Colwell, R.K., and J.A. Coddington, "Estimating Terrestrial Biodiversity Through Extrapolation," *Philosophical Transactions of the Royal Society of London*, vol 345 (1994), pp 101-118.
- Cooperrider, A.Y., R.J Boyd, and H.R. Stuart, eds., *Inventory and Monitoring of Wildlife Habitat* (U.S. Department of the Interior [USDI], Bureau of Land Management, Denver Service Center, 1986).
- Council on Environmental Quality (CEQ), *Incorporating Biodiversity Considerations Into Environmental Impact Analysis Under the National Environmental Policy Act* (Executive Office of the President, CEQ, Washington, DC, 1993).
- Croonquist, M.J., and R.P. Brooks, "Use of Avian and Mammalian Guilds as Indicators of Cumulative Impacts in Riparian-Wetland Areas," *Environmental Management*, vol 15 (1991), pp 701-714.
- Crow, T.R., "Biological diversity and silvicultural systems," pp 180-185 in *Silvicultural Challenges and Opportunities in the 1990's*, Proceedings of the National Silviculture Workshop (USDA Forest Service, Washington, DC, 1989).
- Culatta, E., "Biological Immigrants Under Fire," *Science*, vol 254 (1991), pp 1444-1449.
- Davis, J.W., "Snags are for Wildlife," pp 4-9 in Davis, J.W., G.A. Goodwin, and R.A. Ockenfels, eds., *Snag Habitat Management: Proceedings of a Symposium*, TR RM-99 (USDA Forest Service 1983).
- DeAngelis, D.L., and J.C. Waterhouse, "Equilibrium and Non-Equilibrium Concepts in Ecological Models," *Ecological Monographs*, vol 57 (1987), pp 1-21.
- Diersing, V.E., R.B. Shaw, and D.J. Tazik, "U.S. Army Land Condition-Trend Analysis (LCTA) Program," *Environmental Management*, vol 16 (1992), pp 405-414.
- Diersing, V.E., R.B. Shaw, S.D. Warren, and E.W. Novak, "A User's Guide for Estimating Allowable use of Tracked Vehicles on Nonwooded Military Training Lands," *Journal of Soil and Water Conservation*, vol 43 (1988), pp 191-195.
- Douglass, R.J., "Assessment of the Use of Selected Rodents in Ecological Monitoring," *Environmental Management*, vol 13 (1989), pp 355-363.
- Dunning, J.B., "Bachman's Sparrow," in A. Polle, P. Stettenheim, and F. Gill eds., *The Birds of North America*, No. 38 (The Academy of Natural Sciences, Washington, DC, 1993).
- Echternacht, A.C. and L.D. Harris, "The Fauna and Wildlife of the Southeastern United States," in W.H. Martin, S.G. Boyce, and A.C. Echternacht, eds., *Biodiversity of the Southeastern United States: Lowland Terrestrial Communities* (John Wiley & Sons, Inc., 1993), pp 81-116.
- Ehrlich, P.R., D.S. Dobkin, and D. Wheye, *The Birders Handbook: A Field Guide to the Natural History of North American Birds* (Simon & Schuster Inc., 1988).
- Ehrlich, P.R., and E.O. Wilson, "Biodiversity Studies: Science and Policy," *Science*, vol 253 (1991), pp 758-762.

- Eisenberg, J., "The Gopher Tortoise as a Keystone Species," in R.J. Bryant and R. Franz eds., *Proceedings 4th Annual Meeting Gopher Tortoise Council* (Valdosta, GA, 1983), pp 1-4.
- Eisenmann, E., "Thirty-Second Supplement to the American Ornithologists' Union Check-List of North American Birds," *Auk*, vol 90 (1973), pp 411-419.
- Fager, E.W., "Diversity - A Sampling Study," *American Naturalist*, vol 106 (1972), pp 293-310.
- Fager, L.F., J.C. Capp, and J.L. Sheppard, "Wildlife Requirements and Uses of Snags and Dead/Down Trees on Forested Land in Colorado," Pages 413-417 in R.L. Hoover and D.L. Wills, editors, *Managing Forested Lands for Wildlife*, Colorado Division of Wildlife (Denver, CO, 1984).
- Fisher, R.A., A.S. Corbet, and C.B. Williams, "The Relation Between the Number of Species and the Number of Individuals in a Random Sample of an Animal Population," *Journal of Animal Ecology*, vol 12 (1943), pp 42-58.
- Flather, C.H., L.A. Joyce, and C.A. Bloomgarden, *Species Endangerment Patterns in the United States*, General TR RM-241 (USDA Forest Service, 1994).
- Forman, R.T.T., and M. Godron, "Patches and Structural Components for a Landscape Ecology," *BioScience*, vol 31 (1981), pp 733-740.
- Franklin, J.F., "Structural and Functional Diversity in Temperate Forests," pp 166-175 in E.O. Wilson and F.F. Peter, eds., *Biodiversity* (National Academy Press, Washington, DC, 1988).
- Gerard, P.W., *Agricultural Practices, Farm Policy, and the Conservation of Biological Diversity*, Biological Science Report 4 (USDI, National Biological Service, June 1995).
- Hardin, E.D., and D.L. White, "Rare Vascular Plant Taxa Associated with Wiregrass (*Aristida stricta*) in the Southeastern United States," *Natural Areas Journal*, vol 9 (1989), pp 234-245.
- Harris, L.D., "The Faunal Significance of Fragmentation of Southeastern Bottomland Forests," pp 126-134 in D.D. Hook and R. Lea, eds., *The Forested Wetlands of the Southeastern United States, Proceedings of the Symposium*, sponsored by The Man and the Biosphere Program, USDA Southeastern Forest Experiment Station, Clemson University, and North Carolina State University, July 12-14 (Orlando, FL, 1988).
- Harris, L.D., and K. Atkins, "Faunal Movement Corridors in Florida," W.E. Hudson ed. *Landscape Linkages and Biodiversity* (Island Press, Covelo, CA, 1991), pp 117-134.
- Hendrix, P.F., "Nearctic Earthworm Fauna in the Southern USA: Biodiversity and Effects on Ecosystem Processes," *Biodiversity and Conservation*, vol 5 (1996), pp 223-234.
- Hill, M.O., "Diversity and Evenness: A Unifying Notation and Its Consequences," *Ecology*, vol 54 (1974), pp 427-432.

- Hooper, R.G., A.F. Robinson, and J.A. Jackson, *The Red-Cockaded Woodpecker: Notes on Life History and Management*, USDA Forest Service Southeastern Region, General Report SA-GR9 (1990).
- Horn, H.S., "Measurement of 'Overlap' in Comparative Ecological Studies," *American Naturalist*, vol 100 (1966), pp 419-424.
- Hunter, W.C., "Single Species Versus Community and Ecosystem Management: Their Impact on Biological Diversity," pp 302-314 in Majumdar, S.K., F.K. Brenner, J.E. Lovich, J.F. Schalles, and E.W. Miller, eds., *Biological Diversity: Problems and Challenges* (Pennsylvania Academy of Science, Easton, PA, 1994).
- Hurlbert, S.H., "The Non-Concept of Species Diversity: A Critique and Alternative Parameters," *Ecology*, vol 52 (1971), pp 577-586.
- Huston, M.A., *Biological Diversity* (Cambridge University Press, NY, 1994).
- Jaccard, P., "Nouvelles Recherches sur la Distribution Florale," *Bulletin Societe Vaudoise des Sciences Naturelles*, No. 44 (1908), pp 223-270.
- Jackson, D.R., and E.R. Miltrey, "The Fauna of Gopher Tortoise Burrows," in J.E. Diemer et al., eds., *Proceedings of the Gopher Tortoise Relocation Symposium*, Florida Game and Freshwater Fish Commission (Tallahassee, 1989), pp 86-98.
- Johnson, F.L., C.M. Allen, M.D. Proctor, R.A. Thompson, and G.D. Schnell, *Floral Inventory of Fort Polk, Louisiana*, Final Report to USACERL (April 1993).
- Johnson, R.A., "Application of the Guild Concept to Environmental Impact Analysis of Terrestrial Vegetation," pp 161-177 in W.D. Severinghaus and T.D. James eds., *Proceedings: Conference on Applications of the Guild Concept to Environmental Management*, Technical Manuscript N-86/07/ADA167190 (USACERL, February 1986).
- Jones, K.B., *Distribution, Ecology, and Habitat Management of the Reptiles and Amphibians of the Hualapai-Aquarius Planning Area, Mohave and Yavapai Counties, AZ*, Technical Note 353 (USDI, Bureau of Land Management, Denver, CO, 1981).
- Kaczor, S.A., and D.C. Harnett, "Gopher Tortoise (*Gopherus polyphemus*) Effects on Soils and Vegetation in a Florida Sandhill Community," *American Midland Naturalist*, vol 123 (1990), pp 100-111.
- Karr, J.R., "Within- and Between-Habitat Avian Diversity in African and Neotropical Lowlands Habitats," *Ecological Monographs*, vol 46 (1976), pp 457-481.
- Kempton, R.A., and L.R. Taylor, "Models and Statistics for Species Diversity," *Nature*, vol 262 (1976), pp 818-820.
- Kendeigh, S.C., *Animal Ecology* (Prentice-Hall, Inc., Englewood Cliffs, NJ, 1961).

- Kosztarab, M., and C.W. Schaefer, "Conclusions," pp 241-247 in Kosztarab, M., and C.W. Schaefer, eds., *Systematics of the North American Insects and Arachnids: Status and Needs*, Information Series 90-1 (Virginia Agricultural Experiment Station, Blacksburg, VA, 1990).
- Krebs, C.J., *Ecological Methodology* (Harper Collins Publishers, NY, 1989).
- Krusac, D.L. and J.M. Dabney, "Red-Cockaded Woodpecker Recovery: An Ecological Approach to Managing Biological Diversity," *Transactions of the 59th North American Wildlife and Natural Resources Conference*, no. X (1994), pp 1-9.
- Krzysik, A.J., *Biodiversity and the Threatened / Endangered / Sensitive Species of Fort Irwin, CA*, TR EN-94/07/ADA291289 (USACERL, September 1994).
- Lack, D., *Darwin's Finches* (Cambridge University Press, Cambridge, 1947).
- Lagler, K.F., J.E. Bardach, R.M. Miller, and D.R. May Passino, *Ichthyology* (John Wiley & Sons, NY, 1977).
- Landres, P.B., "Guild Applications to Modern Management Problems," pp 48-49 in W.D. Severinghaus and T.D. James, eds., *Proceedings: Conference on Applications of the Guild Concept to Environmental Management*, Technical Manuscript N-86/07/ADA167190 (USACERL, February 1986).
- Landres, P.B., "Ecological Uses of Vertebrate Indicator Species: A Critique," *Conservation Biology*, vol 2 (1988), pp 316-328.
- Landres, P.B., "Temporal Scale Perspectives in Managing Biological Diversity," pp 292-307 in *Biological Diversity in Wildlife Management*, Reprint of Special Session 5, Transactions of the 57th North American Wildlife and Natural Resources Conference (Wildlife Management Institute, Washington, DC, 1992).
- Leopold, A., *Game Management* (Charles Scribners, NY, 1933).
- Lipske, M., "From War Games to Wildlife Gains," *National Wildlife*, vol 33 (1995), pp 46-51.
- Ludwig, J.A., and J.F. Reynolds, *Statistical Ecology: A Primer on Methods and Computing* (John Wiley & Sons, 1988).
- MacArthur, R.H., "Patterns of Species Diversity," *Biological Review*, vol 40 (1965), pp 510-533.
- MacArthur, R.H., and E.O. Wilson, *The Theory of Island Biogeography* (Princeton University Press, Princeton, NJ, 1967).
- MacClintock, L., R.F. Whitcomb, and B.L. Whitcomb, "Evidence for the Value of Corridors and Minimization of Isolation in Preservation of Biotic Diversity," *American Birds*, vol 31 (1977), pp 6-12.

- Magnussen, S., and T.J.B. Boyle, "Estimating Sample Size for Inference About the Shannon-Weaver and the Simpson Indices of Species Diversity," *Forest Ecology and Management*, vol 78 (1995), pp 71-84.
- Magurran, A.E., *Ecological Diversity and its Measurement* (Princeton University Press, Princeton, NJ, 1988).
- Martin, R.S., *Community Characterization Abstract, Atlantic Coastal Plain Wet-Mesic Longleaf Pine Savannah*, The Nature Conservancy, Southeast Regional Office (Chapel Hill, NC, 1992).
- Martin, C.O., R.A. Fischer, M.G. Harper, D.J. Tazik, and A. Trame, *Regional Strategies for Managing Threatened and Endangered Species Habitats: A Concept Plan and Status Report*, Technical Report SERDP-96-1 (U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 1996).
- Mills, L.S., M.E. Soule, and D.F. Doak, "The Keystone-Species Concept in Ecology and Conservation," *BioScience*, vol 43 (1993), pp 219-224.
- Monk, C.D., "Tree Species Diversity in the Eastern Deciduous Forest With Particular Reference to North Central Florida," *American Naturalist*, vol 101 (1967), pp 173-187.
- Mooney, H.A., and J. Drake, eds. *Ecology of Biological Invasions of North America and Hawaii* (Springer-Verlag, NY, 1986).
- Morisita, M., "Measuring of Interspecific Association and Similarity Between Communities," *Memoirs Faculty Kyushu University, Series E*, vol 3 (1959), pp 65-80.
- Morrison, M.L., "Bird Populations as Indicators of Environmental Change," *Current Ornithology*, vol 3 (1986), pp 429-451.
- Myers, N., *The Sinking Ark* (Pergamon Press, NY, 1979).
- National Environmental Policy Act (NEPA) of 1969 (Public Law 91-190).
- Norton, B.G., and R.E. Ulanowicz, "Scale and Biodiversity Policy: A Hierarchical Approach," *Ambio*, vol 21 (1992), pp 244-249.
- Noss, R.F., "A Regional Landscape Approach to Maintain Diversity," *BioScience*, vol 33 (1983), pp 700-706.
- Noss, R.F., "The Longleaf Pine Landscape of the Southeast: Almost Gone and Almost Forgotten," *Endangered Species Update*, vol 5 (1988), pp 1-8.
- Noss, R.F., "Longleaf Pine and Wiregrass: Keystone Components of an Endangered Ecosystem," *Natural Areas Journal*, vol 9 (1989), pp 211-213.
- Noss, R.F., "Indicators for Monitoring Biodiversity: A Hierarchical Approach," *Conservation Biology*, vol 4 (1990), pp 355-364.

- O'Connell, M.A., and R.F. Noss, "Private Land Management for Biodiversity Conservation," *Environmental Management*, vol 16 (1992), pp 435-450.
- Odum, E.P., *Fundamentals of Ecology* (W.B. Saunders Company, Philadelphia, PA, 1971).
- Odum, E.P., "Conservation of Biodiversity," pp 18-25 in Majumdar, S.K., F.K. Brenner, J.E. Lovich, J.F. Schalles, and E.W. Miller, eds. *Biological Diversity: Problems and Challenges* (Pennsylvania Academy of Science, Easton, PA, 1994).
- Olembo, R., "Importance of Microorganisms and invertebrates as Components of Biodiversity," pp 7-15 in D.L. Hawksworth, ed., *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*, Proceedings of the First Workshop on the Ecological Foundations of Sustainable Agriculture (WEFSA 1), London (C.A.B International 1991).
- Office of Technology Assessment (OTA), *Technologies to Maintain Biodiversity* (U.S. Government Printing Office, Washington, DC, 1987).
- Partners in Flight, 1991 Annual Report (Information and Education Working Group and the National Fish and Wildlife Foundation, Washington, DC), vol 2, no. 1 (1991).
- Patil, G.P., and C. Taillie, "Ecological Diversity: Concepts, Indices, and Applications," *Proceedings of the 9th International Biometric Conference* (Boston, MA, 1976), pp 383-411.
- Patil, G.P., and C. Taillie, "An Overview of Diversity," pp 3-27 in J.F. Grassle, G.P. Patil, W.K. Smith, and C. Taillie, eds., *Ecological Diversity in Theory and Practice*, Statistical Ecology: Volume 6 (International Co-operative Publishing House, Burtonsville, MD, 1979).
- Patil, G.P., and C. Taillie, "Diversity as a Concept and Its Measurement," *Journal of the American Statistical Association*, vol 77 (1982), pp 548-561.
- Peet, R.K., "The Measurement of Species Diversity," *Annual Review of Ecological Systematics*, vol 5 (1974), pp 285-307.
- Peet, R.K., "Relative Diversity Indices," *Ecology*, vol 56 (1975), pp 496-498.
- Pickett, S.T.A., and J.N. Thompson, "Patch Dynamics and the Design of Nature Reserves," *Biological Conservation*, vol 13 (1978), pp 27-37.
- Pielou, E.C., "Shannon's Formula as a Measure of Species Diversity: Its Use and Misuse," *American Naturalist*, vol 100 (1966), pp 463-465.
- Pielou, E.C., *Ecological Diversity* (John Wiley & Sons, NY, 1975).
- Platt, W.J., J.S. Glitzenstein, and D.R. Streng, *Restoration and Management of Fire-Adapted Communities: An Experimental Study of Longleaf Pine Forests*. Unpublished Annual Report to the Florida Freshwater Fish Commission (Tallahassee, FL, 1989).

- Prance, G.H., "A Comparison of the Efficacy of Higher Taxa and Species Numbers in the Assessment of Biodiversity in the Neotropics," *Philosophical Transactions of the Royal Society of London*, vol 345 (1994), pp 89-99.
- Price, D.L., A.B. Anderson, W.R. Whitworth, and P.J. Guertin, *Land Condition Trend Analysis Data Summaries: Preliminary Data Applications*, TR 95/39/ADA300753 (USACERL, September 1995).
- Ratcliff, D.A., "Selection of Important Areas for Conservation in Great Briton: The Nature Conservancy Council's Approach," in M.B. Usher, ed. *Wildlife Conservation Evaluation* (Chapman and Hall, London, United Kingdom, 1986), pp 136-159.
- Raven, P.H., and E.O. Wilson, "A Fifty-Year Plan for Biodiversity Studies," *Science*, vol 258 (1992), pp 1099-1100.
- Rice, C.G., R.W Hansen, and S. Demarais, *Analysis of LCTA Methods for Inventory and Monitoring Birds and Small Mammals on Army Lands in the Southwestern United States*, Draft Final Report Submitted to USACERL (Texas Tech University, Department of Range and Wildlife Management, December 1995).
- Riley, F.L., *A Trip Through the Piney Woods*, Publications of the Mississippi Historical Society, vol 9 (1906).
- Robbins, L.E., and R.L. Meyers, *Seasonal Effects of Prescribed Burning in Florida: A Review*, Tall Timbers Research, Inc. Miscellaneous Publication No. 8 (Tallahassee, FL, 1992).
- Robertson, F.D., *Ecosystem Management of the National Forests and Grasslands*, USDA Forest Service, Washington, DC, 1330-1 policy letter, June 4, 1992.
- Root, R.B., "The Niche Exploitation Pattern of the Blue-Gray Gnatcatcher," *Ecological Monographs*, vol 37 (1967), pp 317-350.
- Ruggiero, L.F., G.D. Hayward, and J.R. Squires, "Viability Analysis in Biological Evaluations: Concepts of Population Viability Analysis, Biological Population, and Ecological Scale," *Conservation Biology*, vol 8 (1994), pp 364-372.
- Samson, F.B., "Conserving Biological Diversity in Sustainable Ecological Systems," pp 308-320 in *Biological Diversity in Wildlife Management*, Reprint of Special Session 5, Transactions of the 57th North American Wildlife and Natural Resources Conference (Wildlife Management Institute, Washington, DC, 1992).
- Savage, J.M., "Systematics and the Biodiversity Crisis," *BioScience*, vol 45 (1995), pp 673-679.
- Schreiber, E.R., P.K. Kirby, M.K. Chawla, and D.L. Price, *Land Condition Trend Analysis Data and NEPA Documentation* (USACERL, unpublished).
- Scott, M., "Bats at Bliss," *Soldiers*, vol 51, no. 4 (1996), p 45.

- Senseman, G.M., S.A. Tweddale, A.B. Anderson, and C.F. Bagley, *Correlation of Land Condition Trend Analysis (LCTA) Rangeland Cover Measures to Satellite-Imagery-Derived Vegetation Indices*, TR 97/07 (USACERL, October 1996).
- Severinghaus, W.D., "Guild Theory Development as a Mechanism for Assessing Environmental Impact," *Environmental Management*, vol 5 (1981), pp 187-190.
- Severinghaus, W.D., and W.D. Goran, *Effects of Tactical Vehicle Activity on the Mammals, Birds, and Vegetation at Fort Lewis, Washington*, TR N-116 (USACERL, November 1981).
- Severinghaus, W.D., R.E. Riggins, and W.D. Goran, *Effects of Tracked Vehicle Activity on Terrestrial Mammals, Birds, and Vegetation at Fort Knox, KY*, Special Report N-77 (USACERL, July 1979).
- Shannon, C.E., and W. Weaver, *The Mathematical Theory of Communication* (The University of Illinois Press, Urbana, 1949).
- Sharitz, R.R., L.R. Boring, D.H. Van Lear, and J.E. Pinder, "Integrating Ecological Concepts with Natural Resource Management of Southern Forests," *Ecological Applications*, vol 2 (1992), pp 226-237.
- Shaw, R.B., and V.E. Diersing, "Allowable Use Estimates for Tracked Vehicular Training on Pinon Canyon Maneuver Site, Colorado, USA," *Environmental Management*, vol 13 (1989), pp 773-782.
- Short, H.L., and K.P. Burnham, *Technique for Structuring Wildlife Guilds to Evaluate Impacts on Wildlife Communities*, Special Scientific Report - Wildlife 244 (USDI, Fish and Wildlife Service, 1982).
- Sibley, C.C., and L.L. Short, Jr., "Hybridization in the Buntings of the Great Plains," *Auk*, vol 76 (1959), pp 443-463.
- Simpson, E.H., "Measurement of Diversity," *Nature*, vol 163 (1949), pp 688.
- Society of American Foresters, *Forest Cover Types of the United States and Canada*, F.H. Eyre, ed. (Society of American Foresters, Washington, DC, 1980).
- Solbrig, O.T., "The Origin and Function of Biodiversity," *Environment*, vol 33 (1991), pp 17-38.
- Sorenson, T.A., "A Method of Establishing Groups of Equal Amplitude in Plant Sociology Based on Similarity of Species Content, and it's Application to Analyses of the Vegetation on Danish Commons," *K. dan. Vidensk. Selsk. Biol. Skr.*, vol 5 (1949), pp 1-34.
- Speake, D.W., "Gopher Tortoise," in R.H. Mount, ed., *Vertebrate Animals of Alabama in Need of Special Attention* (Alabama Agricultural Experiment Station, Auburn University, 1986), pp 41-42.
- Spellerberg, I.F., *Monitoring Ecological Change* (Cambridge Univ. Press, NY, 1993).

- Spellerberg, I.F., and J.W.D. Sawyer, "Standards for Biodiversity: A Proposal Based on Biodiversity Standards for Forest Plantations," *Biodiversity and Conservation*, vol 5 (1996), pp 447-459.
- Steiner, R.P., "Statistical and Theoretical Aspects of Diversity Indices," pp 50-63 in Majumdar, S.K., F.K. Brenner, J.E. Lovich, J.F. Schalles, and E.W. Miller, eds. *Biological Diversity: Problems and Challenges* (Pennsylvania Academy of Science, Easton, PA, 1994).
- Stewart, W.P.D., "The Importance to Sustainable Agriculture of Biodiversity Among Invertebrates and Microorganisms," pp 3-5 in D.L. Hawksworth, ed., *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*, Proceedings of the First Workshop on the Ecological Foundations of Sustainable Agriculture (WEFSA 1), London (C.A.B International 1991).
- Stohlgren, T.J., and J.F. Quinn, "An Assessment of Biotic Inventories in Western U.S. National Parks," *Natural Areas Journal*, vol 12 (1992), pp 145-154.
- Szaro, R., "Guild Management: An Evaluation of Avian Guilds as a Predictive Tool," *Environmental Management*, vol 10 (1986), pp 681-688.
- Tazik, D.J., J.D. Cornelius, D.M. Herbert, T.J. Hayden, and B.R. Jones, *Biological Assessment of the Effects of Military Associated Activities on Endangered Species at Fort Hood, Texas*, Special Report EN-93/01/ADA263489 (USACERL, December 1992a).
- Tazik, D.J., S.D. Warren, V.E. Diersing, R.B. Shaw, R.J. Brozka, C.A. Bagley, and W.R. Whitworth, *U.S. Army Land Condition-Trend Analysis (LCTA) Plot Inventory Field Methods*, TR N-92/03/ADA247931 (USACERL, February 1992b).
- Temple, S.A., and J.A. Weins, "Bird Populations and Environmental Changes: Can Birds Be Bio-Indicators?," *American Birds*, vol 43 (1989), pp 260-270.
- Thomas, J.W., *New Directions for the Forest Service*, Statement before the Subcommittee on National Parks, Forests, and Public Lands and the Subcommittee on Oversight and Investigations, Committee on Natural Resources, U.S. House of Representatives, February 3, 1994.
- Thurow, T.L., S.D. Warren, and D.H. Carlson, "Tracked Vehicle Traffic Effects on the Hydrologic Characteristics of Central Texas Rangeland," *Transactions of the American Society of Agricultural Engineers*, vol 36 (1993), pp 1645-1650.
- Trame, A., and D.J. Tazik, *The Implications of Ecosystem Management for Threatened and Endangered Species Conservation by the U.S. Army*, TR 95/27/ADA302406 (USACERL, September 1995).
- Trumbull, V.L., P.C. Dubois, R.J. Brozka, and R. Guyette, "Military Camping Impacts on Vegetation and Soils of the Ozark Plateau," *Journal of Environmental Management*, vol 40 (1994), pp 329-339.

Turner, M.G., R.H. Gardner, and R.V. O'Neill, "Ecological Dynamics at Broad Scales," *Science and Biodiversity Policy*, BioScience Supplement (1995), pp S29-S35.

Urban, D.L., R.V. O'Neill, and H.H. Shugart, "Landscape Ecology," *BioScience*, vol 37 (1987), pp 119-127.

USACERL, *GRASS 4.1 User's Reference Manual* (USACERL, 1993).

USACERL, *Biological Assessment of Army-Wide Management Guidelines for the Red-cockaded Woodpecker*, Special Report No. EN-94/03 (USACERL, February 1994a).

USACERL, *Environmental Assessment of Army-Wide Management Guidelines for the Red-cockaded Woodpecker*, Special Report No. EN-94/04 (USACERL, January 1994b).

U.S. Department of the Army, *Facilities Engineering and Housing Annual Summary of Operations, Fiscal Year 1989* (Office of the Assistant Chief of Engineers, U.S. Army Engineering and Housing Support Center, Fort Belvoir, VA, 1989).

USDI, *Ecosystem Management in the BLM, A Process to Promote Biological Diversity and Sustainable Development*, Draft concept paper for public comment (USDI, Washington, DC, March 1993).

USDI, *Ecosystem Approach to Fish and Wildlife Conservation*, Memorandum to all Fish and Wildlife Service employees (USDI, Washington, DC, March 1994).

U.S. House of Representatives, *National Biological Diversity Conservation and Environmental Research Act*, U.S. House of Representatives Report 101-901 (U.S. Government Printing Office, Washington, DC, 1990).

Vaughan, T.A., *Mammalogy* (Saunders College Publishing, Philadelphia, PA, 1978).

Verner, J., "The Guild Concept Applied to Management of Bird Populations," *Environmental Management*, vol 8 (1984), pp 1-14.

Walker, B.H., "Biodiversity and Ecological Redundancy," *Conservation Biology*, vol 6 (1992), pp 18-23.

Warner, R.E., J.D. Brawn, and E.J. Heske, *Land Condition Trend Analysis (LCTA): Evaluation of Wildlife Monitoring Methods*, Illinois Natural History Survey, Center for Wildlife Ecology, Final Report to USACERL (January 1996).

Warren, S.D., V.E. Diersing, P.J. Thompson, and W.D. Goran, "An Erosion-Based Land Classification System for Military Installations," *Environmental Management*, vol 13 (1989), pp 251-257.

Warren, S.D., and C.F. Bagley, "SPOT Imagery and GIS in Support of Military Land Management," *Geocarto International*, vol 1 (1992), pp 35-43.

Waters, N.M., "Diversity Indices and their Biological Implications," pp 64-75 in Majumdar, S.K., F.K. Brenner, J.E. Lovich, J.F. Schalles, and E.W. Miller, eds. *Biological Diversity: Problems and Challenges* (Pennsylvania Academy of Science, Easton, PA, 1994).

Welty, J.C., *The Life of Birds* (Saunders College Publishing, Philadelphia, PA, 1982).

West, H.W., and H.H. Allen, *A Technique for Quantifying Forest Stands for Management Evaluations*, TR M-71-9 (U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS, 1971).

Westman, W.E., *Ecology, Impact Assessment, and Environmental Planning* (John Wiley & Sons, NY, 1985).

Westman, W.E., "Managing for Biodiversity," *BioScience*, vol 40 (1990), pp 26-33.

Whittaker, R.H., "Evolution and Measurement of Species Diversity," *Taxon*, vol 21 (1972), pp 213-251.

Whitworth, W.R., *Abundance, Distribution, and Selected Characteristics of Nesting Raptors on the Fort Sill Military Reservation: 1987 to 1992*, TR 95/45/ADA302743 (USACERL, September 1995).

Wilcox, B.A. and D.D. Murphy, "Conservation Strategy: The Effects of Fragmentation on Extinction," *American Naturalist*, vol 125 (1985), pp 879-887.

Wilson, E.O., "The Current State of Biological Diversity," pp 3-18 in E.O. Wilson and F.F. Peter, eds., *Biodiversity* (National Academy Press, Washington, DC, 1988).

Yodzis, P., "Environment and Trophodiversity," pp 26-38 in R.E. Ricklefs and D. Schluter eds., *Species Diversity in Ecological Communities* (University of Chicago Press, 1993).

Uncited:

Hammond, P.M., "Practical Approaches to the Estimation of the Extent of Biodiversity in Speciose Groups," *Philosophical Transactions of the Royal Society of London*, vol 345 (1994), pp 119-136.

Hansen, A.J., T.A. Spies, F.J. Swanson, and J.L. Ohmann, "Conserving Biodiversity in Managed Forests," *BioScience*, vol 41 (1991), pp 382-392.

Kirkland, G.L. Jr., A.F. Rhoads, and K.C. Kim, "Perspectives on Biodiversity in Pennsylvania and its Maintenance," *Journal of the Pennsylvania Academy of Science*, vol 64 (1990), pp 155-159.

Lovejoy, T.E., "The Quantification of Biodiversity: An Esoteric Quest or a Vital Component of Sustainable Development?" *Philosophical Transactions of the Royal Society of London*, vol 345 (1994), pp 81-87.

Simpson, B.B. and J. Cracraft, "Systematics: The Science of Biodiversity," *BioScience*, vol 45 (1995), pp 670-672.

USACERL DISTRIBUTION

Chief of Engineers

ATTN: CEHEC-IM-LH (2)
 ATTN: CEHEC-IM-LP (2)
 ATTN: CECC-R
 ATTN: CERD-L

Army Headquarters

ATTN: DAIM-ED-N (5)
 ATTN: DAMO-TRO
 ATTN: ANOP
 ATTN: AMSTE-EQ
 ATTN: SFIM-AEC-ECN
 ATTN: ATIC-CTS
 ATTN: FKEN-EN
 ATTN: AEAGC-TD-MO
 ATTN: EAGC-TD-RMD
 ATTN: APOP-TR
 ATTN: APEN-EV

US Army Europe

ATTN: AEAEN-ENVR 09114
 100th Support Group
 ATTN: AETT-EN-DPW 09114
 CMTC Hohenfels 09173
 ATTN: AETHH-DPW

FORSCOM

Fts Gillem & McPherson 30330
 ATTN: AFOP-TE
 ATTN: AFOP-TSR
 ATTN: AFPI-ENE

Installations:

Fort Indiantown Gap 17003
 ATTN: AFKA-ZQ-DE-E
 Fort AP Hill 22427
 ATTN: ANAP-PWE
 ATTN: AFZM-FHE
 Fort McPherson 30330
 ATTN: AFZK-EH-E
 Fort Riley 66442
 ATTN: AFZN-DE-V-N
 Fort Polk 71459
 ATTN: AFZH-DE-EN
 Fort Sam Houston 78234
 ATTN: AFZG-DE-EM
 Fort Lewis 98433
 ATTN: AFZH-DE-Q
 Fort Carson 80913
 ATTN: AFZC-ECM-NR
 Fort Bragg 28307
 ATTN: AFZA-PW-DW
 Fort Campbell 42223
 ATTN: AFZB-DPW-E
 Fort McCoy 54656
 ATTN: AFZR-DE-E
 Fort Pickett 23824
 ATTN: AFZA-FP-E
 Fort Stewart 31314
 ATTN: AFZP-DEV
 Fort Buchanan 00934
 ATTN: AFZK-B-EHE

Fort Devens 01433

ATTN: AFZD-DEM
 Fort Drum 13602
 ATTN: AFZS-EH-E
 Fort Irwin 92310
 ATTN: AFZJ-EHE-EN
 Fort Hood 76544
 ATTN: AFZF-DE-ENV
 Fort Hunter Liggett 93928
 ATTN: AFZW-HE-DE
 Yakima Tng Center 98901-5000
 ATTN: AFZH-Y-ENR
 Fort Dix 08640
 ATTN: ATZD-EH

TRADOC

Fort Monroe 23651
 ATTN: ATBO-FE

Installations:

Fort Lee 23801
 ATTN: ATZM-PTS-T
 Fort Jackson 29207
 ATTN: ATZJ-PWN
 Fort Gordon 30905
 ATTN: ATZH-DIE
 Fort Benning 31905
 ATTN: ATZB-PWN
 Fort McClellan 36205
 ATTN: ATZN-EM
 Fort Rucker 36362
 ATTN: ATZQ-DPW-EN
 Fort Leonard Wood 64573
 ATTN: ATZT-DPW-EE
 Fort Leavenworth 66027
 ATTN: ATZL-GCE
 Fort Bliss 79916
 ATTN: ATZC-DOE
 Carlisle Barracks 17013
 ATTN: ATZE-DPW-E
 Fort Eustis 23604
 ATTN: ATZF-PWE
 Fort Chaffee 72905
 ATTN: ATZR-ZF
 Fort Sill 73503
 ATTN: ATZR-B
 Fort Huachuca 85613
 ATTN: ATZS-EHB
 Fort Knox 40121
 ATTN: ATZK-PWE

USAMC Instal & Svc Activity

ATTN: AMXEN-M 61299
 Rock Island Arsenal
 ATTN: AMSMC-EHR
 ATTN: SMCRI-PWB
 White Sands Missile Range
 ATTN: STEWS-ES-E
 US Army Dugway Proving Ground
 ATTN: STEDP-EPO-CP
 US Army Yuma Proving Ground
 ATTN: STEYP-ES-E

Aberdeen Proving Ground

ATTN: STEAP-SH-ER

National Guard Bureau 20310

ATTN: NGB-ARE
 ATTN: NGB-ARI
 ATTN: NGB-ARO-TS

Army National Guard

Fort Richardson, AK 99505-5800
 Phoenix, AZ 85008-3495
 Sacramento, CA 95826-9101
 Boise, ID 83705-8095
 Jackson, MS 39209
 Camp Shelby, MS 39407-5500
 Oklahoma City, OK 73111-4389
 Draper, UT 84020-1776
 Braggs, OK 74423
 Reading, MA 01867-1999
 Camp Edwards, MA 02542-5003
 Richmond, VA 23219
 Columbia, SC 29201
 Eastover, SC 29244
 St. Augustine, FL 32085
 Starke, FL 32091
 Indianapolis, IN 46241
 Lansing, MI 48913
 Little Falls, MN 56345
 Jefferson, MO 65101
 Camp Roberts, CA 93451
 Camp Robinson, AR 72118-2200

US Military Academy 10996

ATTN: MAEN-EV
 ATTN: DOPS

US Army Research Laboratory

ATTN: AMSRL-OP-SDFE

US Govt Printing Office 20401

ATTN: Rec Sec/Deposit Sec

Defense Technical Info Ctr 22304

ATTN: DTIC-FAB

102
 1/97